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PHYSIOGRAPHY

FOR HIGH SCHOOLS

BY

ROLLIN D. SALISBURY

Professor of Geographic Geology and head of the Department of Geography
in the University of Chicago

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PREFACE

SEVERAL good elementary books on Physical Geography have been published in the last decade or so, and some of them have met with popular favor deservedly. Yet ideas as to what a text-book on this subject should be vary so widely that there has been some demand for a text written on lines which differ from those of any of the books now before the public. The authors of the books already published would, no doubt, differ from the writer of this as much as he differs from them, not only as to the plan which should be followed in a text-book for first or second year high-school pupils, but as to the points upon which emphasis should be laid and the objects to be attained. It is quite possible that the same book is not best for all teachers or for all pupils. The method of one book will doubtless continue to appeal to one teacher, and the method of another to another, and most teachers will probably get the best results from the book which appeals most strongly to them.

This book has been prepared with the purpose of letting the beginner into the method of the science with which the book deals, as well as with the purpose of conveying information to him. It has been prepared with the conviction that the child likes to reason and to follow reasoning, and that reasoning and following reasoning contribute more to his mental growth than the accumulation of great numbers of facts. It has been written with the conviction that the growth of the pupil is more important than facts about physical geography. To those who hold other views, this volume will not appeal.

The illustrations of the book should be regarded by the teacher as vital, and should be studied and interpreted as carefully as the text itself. These illustrations may well be supplemented by other diagrams, photographs, lantern-slides, etc., and should be supplemented by trips to points of interest out of doors, and by such exercises in the laboratory as help (1) to develop new principles, or (2) to illustrate and enforce the principles already developed in the class-room. In the judgment of the writer there is little place for laboratory work which does not contribute to these ends.

In teaching, every efficient teacher will do best, probably, to follow his own method, if he has one in which he has faith. But the author suggests that the method now much used, of talking over with the pupils the subjects as they come up, before assignments are made in the text, is, on the whole, a good one. The work of the class-room, so far as it is given to the text, should be directed toward seeing that the pupil has translated it into *terms of reality;* or, to put it in another way, into *terms of outdoors.* On the other hand, it is a mistake to assume that any one plan should be followed always. Variations of method are often to be encouraged.

Directions for laboratory work do not appear in the text, nor is laboratory material suggested. The omission is intentional, not because laboratory work is regarded as unimportant, but because, in the author's judgment, the effect upon the pupil is best when the laboratory work is suggested by the teacher. In this case it may be adapted to each class, and developed along the lines and to the extent which the apparatus and the time available permit. It is the purpose of the author to issue shortly a booklet on this subject, to accompany this text,— a booklet intended for the teacher, not for the pupil.

A few references are given at the ends of chapters. References to the more technical papers have been omitted for the most part. Further references, if desired by the teachers, can be found in the author's Physiography, Advanced Course, and in other published books on this subject.

The illustrations have been drawn from many sources, usually acknowledged in the text.

The author desires to express his great obligations to Dr. Cowles and Mr. Adams, who have been generous enough to contribute Chapter XIX.

Acknowledgments are due to Mrs. J. P. Cook and Miss Evelyn Matz, who have read parts of the text, and who have made valuable suggestions as to its adaptation to pupils of the grades for which it is intended.

University of Chicago, November, 1907.

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PHYSIOGRAPHY

INTRODUCTION

Definition. Physiography deals with (1) the solid part of the earth, the *lithosphere,* (2) the liquid part of the earth, the water or *hydrosphere,* and (3) the gaseous part of the earth, the air or *atmosphere.* The land, the water, and all animal and plant life are affected by the atmosphere, while the water is related in many ways to the land and to the life of the globe. As to the lithosphere, physiography has to do with its surface only, a surface which has not always had its present form. It has been shaped and re-shaped by winds, rivers, waves, and ice. Volcanic forces, too, have had their part in building it up and tearing it down, and over and over again the outer part of the earth has been warped and wrinkled. It is this ever-changing surface which concerns man and life generally; and physiography has to do chiefly with the surface of the lithosphere and with the relation of air and water to it.

Physiography and geology are closely related. The history of the earth has been written in the rocks for the student of geology, and physiography deals with the latest chapter of that history, the history of the present surface.

Physiography is also related to geography; for while geography is concerned with the distribution of life and human industries, rather than with the physical relations of earth, air, and water, this distribution depends largely upon soil, climate, and natural resources. Physiography not only takes up the physical side of geography, but it also sets forth much of the latest and freshest chapter of geology, a chapter which can never be finished so long as the world continues to change.

Although the solid part of the earth, the water, and the air, seem very distinct from one another, they are in reality not so sharply separated as they seem. The larger part of the water is in the ocean, lakes, and rivers; but some of it has sunk into the soil and rocks, and a little of it is always to be found in the form of vapor, which we cannot see, in the air. So, too, a part of the atmosphere penetrates the soil and rocks of the land, and gases from it are dissolved in the water. Solid matter from the land is found in water, often making it muddy, and dust is always present in the atmosphere. In spite of this mingling, the boundaries between the lithosphere, hydrosphere, and atmosphere are usually well defined.

PART I

THE LITHOSPHERE

CHAPTER I

RELIEF FEATURES

The surface of the earth consists of two great divisions, the land and the sea. The area of the sea is nearly three times that of the land, but the land is of greater interest to man, because it is his home.

The surface of the land is uneven. The lowest lands are below the level of the sea, and the highest point of land (Mt. Everest in the Himalaya Mountains) is between five and six miles above it. The unevenness, or *relief*, of the land surface is therefore not far from six miles. The sea bottom is also uneven, and its relief is a little greater than that of the land. Since the highest points of the land are nearly six miles above the sea, and the lowest parts of the sea bottom about six miles below, *the relief of the surface of the lithosphere is almost twelve miles.* If the surface of the lithosphere were even, there would be no land at all, for then the water of the ocean would cover the whole earth to the depth of about 9,000 feet.

THE GREAT RELIEF FEATURES

If the high lands of the earth were planed down, and if the material were spread over the low lands, so that all parts above the sea had the same height, the land would be a little less than half a mile above the sea. If the sea bottom were made smooth, the depth of the water everywhere would be about two and one-half miles. The continents are therefore nearly three miles higher, on the average, than the bottoms of the ocean basins. *The continents and the ocean basins are the greatest relief features of the earth* (Fig. 1).

About the continents as we know them, there is almost everywhere a belt of shallow water. The sea bottom below this shallow water is the *continental shelf* (Fig. 2), at the outer edge of which there is a steep slope down to the ocean basins. The continental shelves really belong with the continents, not with the ocean basins. These basins are more than full of water, and the overflow from them covers the lower parts of the real continents. If the areas of the continental shelves be added to the continents, the continents, or elevated parts of the lithosphere, would make up about one-third of the earth's surface, and the ocean basins the remaining two-thirds.

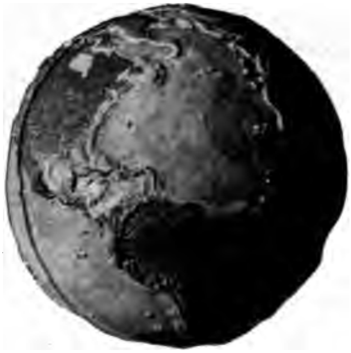


Fig. 1.—Photograph of a relief globe, showing the North Atlantic Basin depressed notably below the continents about it. The vertical scale of the globe is exaggerated.

The ocean basins and the continents are irregular both in shape and distribution. The sunken tracts are far in excess in the southern hemisphere (Fig. 3), while the elevated areas are largely in the northern hemisphere.

The continents. The continents commonly recognized are (1) Eurasia (Europe and Asia), (2) Africa, (3) North America, (4) South America, and (5) Australia. Besides these five, Antarctica may be counted a sixth continent. Greenland, the largest remaining body of land, is regarded as an island.

The great land areas are not connected, as any map of the earth or any globe plainly shows. The sea, on the other hand, is continuous, though its parts bear separate names, as Atlantic, Pacific, etc.

Grouping of the continents. The northern hemisphere contains more than twice as much land as the southern. If the earth be divided into two hemispheres, one with its center in England, and the other in New Zealand (Fig. 3), the first would contain about six-sevenths of all the land, and might be called the *land hemisphere,* while the other would contain only about one-seventh of the land, and might be called the *water hemisphere*. Even in the land hemisphere, however, the water would cover rather more than half the surface, while in the water hemisphere it would cover about fourteen-fifteenths of it. Since the northern hemisphere contains two-thirds of the land, and a still larger proportion of the productive land, it has always supported a vast majority of the human race.

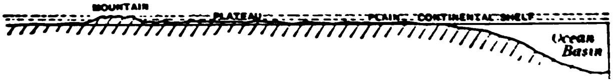


Fig. 2.—Diagram to show the distinction between an elevated continental area and an ocean basin. The steep slope (much exaggerated) at the left of the ocean basin is the line of contact between the two, and is the real border of the continental area. The ocean covers the lower part of the continental tract, namely, the *continental shelf*. The diagram also shows the general relation between low mountains, such as the Appalachians, a low plateau, and a coastal plain. The continental shelf is seen to be a continuation of the coastal plain.

Origin of relief features of the first order. The ocean basins and the continental platforms seem to have been very much as they now are, for millions of years. It is probable that the ocean basins have sunk below the continents, rather than that the continents have been raised above the ocean basins. The reason for this belief is that the earth is cooling, and therefore shrinking, and shrinking means that the outside is getting nearer to the center. This must

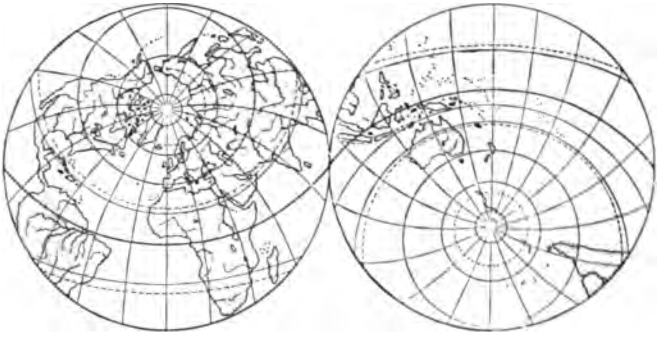
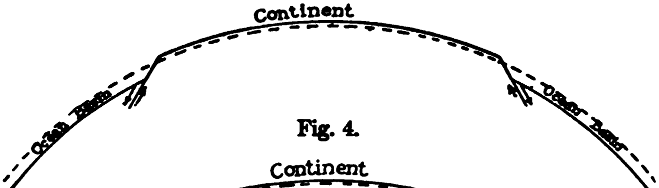


Fig. 3.—Land and water hemispheres.



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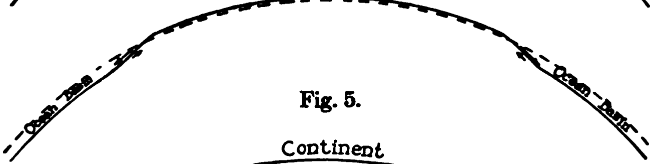

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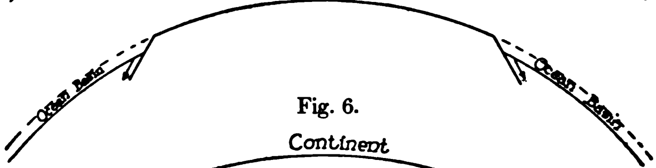

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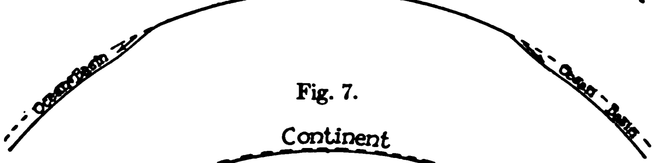

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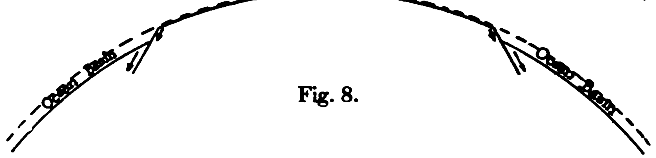


Fig. 8.

Fig. 4.—Diagram representing the conception that the continents were lifted and the ocean basins sunk by movement along definite sliding planes or *fault planes*. The dotted line may be taken to represent a somewhat uniform original surface, which may be looked upon as the surface before continents and ocean basins were developed. The diagram indicates that the continents have risen above this surface, while the ocean basins have sunk below it.

Fig. 5.—This diagram represents the same conception as Fig. 4, except that the movement was by bending, instead of faulting.

Fig. 6.—This diagram represents the same conception as Fig. 4, except that the continental part is represented as not having risen.

Fig. 7.—This diagram represents the same conception as Fig. 5, except that the continental segment has not risen.

Fig. 8.—This diagram represents the same conception as Fig. 6, except that both ocean basin and continental segment are represented as having sunk below the original level, the former more than the latter.

result in a sinking of the surface, though not necessarily at every point. The sinking of the depressed areas or the rise of the elevated areas may be brought about in different ways, some of which are suggested by Figs. 4 to 8.

Past changes. If the sea bottom were to sink, the ocean basins would hold more, and some of the sea-water would be drawn off the continental shelves. If the bottoms of the ocean basins were to go down 600 feet, or a little more, *all* the water would be drawn off the continental shelves, and they would then become land. If the continents were to sink, the waters of the sea would spread farther than now over their borders, and the area of the land would be lessened. The history of the earth teaches that the areas of the ocean and land have changed somewhat from time to time. The lower parts of the continental platforms have been drowned and made into land, over and over; but it is not known that any part of the *deep* ocean basins has ever been land, or that any part of the land was ever beneath a *deep* sea.

RELIEF FEATURES OF THE SECOND ORDER

The more strongly marked features of the continents and the ocean basins are relief features of the *second order*. The continental areas are made up of *plains*, *plateaus*, and *mountains*. Plains are the low lands of the earth, and the plateaus and mountains are the high lands. The relations of these features are shown in Fig. 2.

Plains

Though plains are generally lower than plateaus and mountains, they cannot be defined in terms of height above the sea, for they may be but a few feet above it, or they may be hundreds or even thousands of feet above. If so high as a thousand feet, however, they are generally far from the sea, and distinctly lower than some of the other lands about them.

Plains differ widely among themselves, not only in height, but in position, in size, in shape of surface, in fertility, in origin, and in various other ways. Different names are given to various sorts of plains, the names being intended to turn attention to some one feature. Important classes of large plains are *coastal plains*, which border the sea, and *interior plains*, which are far from the sea, or separated from it by high lands.

Coastal plains occur on the borders of many continents. They are wide in some cases, and narrow in others. A narrow, low plain with a nearly flat surface is shown in Fig. 9. The landward edges of coastal plains are not always so sharply marked as in this illustration.

Plate I represents, in another way, a part of the narrow coastal plain of Oregon. Since illustrations of the sort shown in this plate will be used often in the following pages, the principles on which it is based must be understood. It is called a *contour* or *topographic* map.

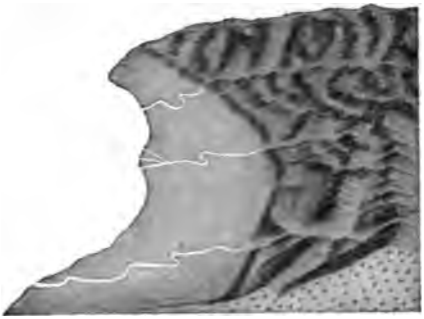


Fig. 9.—A narrow coastal plain.

Explanation of Contour Map

The topographic map shows three sorts of features. These are (1) the shape of the surface, (2) the distribution of water, and (3) the works of man.

The shape of the surface. A land surface may be flat or uneven. If flat, it may be high or low, and if uneven, it may have little relief or much. The topographic map shows how flat or how rough it is.

The height of land is reckoned from sea-level. The heights of many points are measured exactly, and some of them are given on the map in figures. It is desired, however, to give the elevation of all parts of the area mapped, and to show what parts are flat, and what parts have slopes. Not only this, but if there are slopes, it is important to show whether they are gentle or steep. All these things are done by lines called *contour lines*, or simply *contours*. A contour line connects points of the same elevation above sea-level. Thus the contour of 20 feet connects points which are 20 feet above sea-level, the contour of 40 feet connects points which are 40 feet above sea-level, and so on. The vertical distance between two contour lines is the *contour interval.* The contour interval may be 10, 50, 100, or any other number of feet. On the maps of the United States Geological Survey, the contours are printed in brown (Plate I).

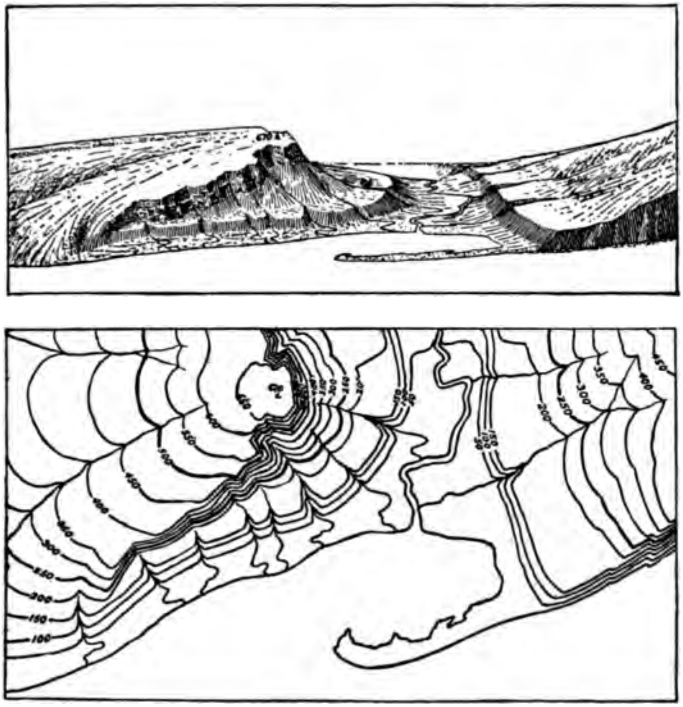


Fig. 10.—Sketch and map of the same area to illustrate the representation of topography by means of contour lines. (U. S. Geol. Surv.)

The manner in which contours express elevation, form, and grade is shown in the sketch and contour map of Fig. 10. The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a sand bar. On each side of the valley is a terrace. From the terrace on the right, a hill rises gradually, while from that on the left the ground ascends steeply, in a *cliff.* Contrasted with this cliff is the gentle descent of the slope at the left. In the map, each of these features is shown by contours directly beneath its positon in the sketch. The following explanation may make clearer the manner in which contours show elevation, form, and grade:

1. We are to remember that *a contour indicates a certain height above sea-level.* In this illustration, the contour interval is 50 feet; therefore the contours are drawn 50, 100, 150, 200 feet, and so on, above sea-level. The 50-foot contour connects all points of the surface 50 feet above the sea, and the 100-foot contour connects all points 100 feet above the sea. In the space between any two contours, the elevation is greater than that of the lower, and less than that of the higher. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace. All points on the terrace are more than 150 but less than 200 feet above the sea. The summit of the higher hill is stated to be 670 feet above the sea, and the contour at 650 feet surrounds it. In this illustration nearly all the contours are numbered; but on most maps this is not possible. Instead, certain contours — say every fifth one — are made heavier and numbered (Pl. I); the height of any contour not numbered may then be known by counting up or down from one that is numbered.

2. **Contours show the forms of slopes.** Since contours are continuous horizontal lines at a given height above the sea, they wind smoothly about smooth surfaces. They run up into ravines, and project out in passing about prominences. The relations of contour curves and angles to the form of the surface can be traced in Fig. 10.

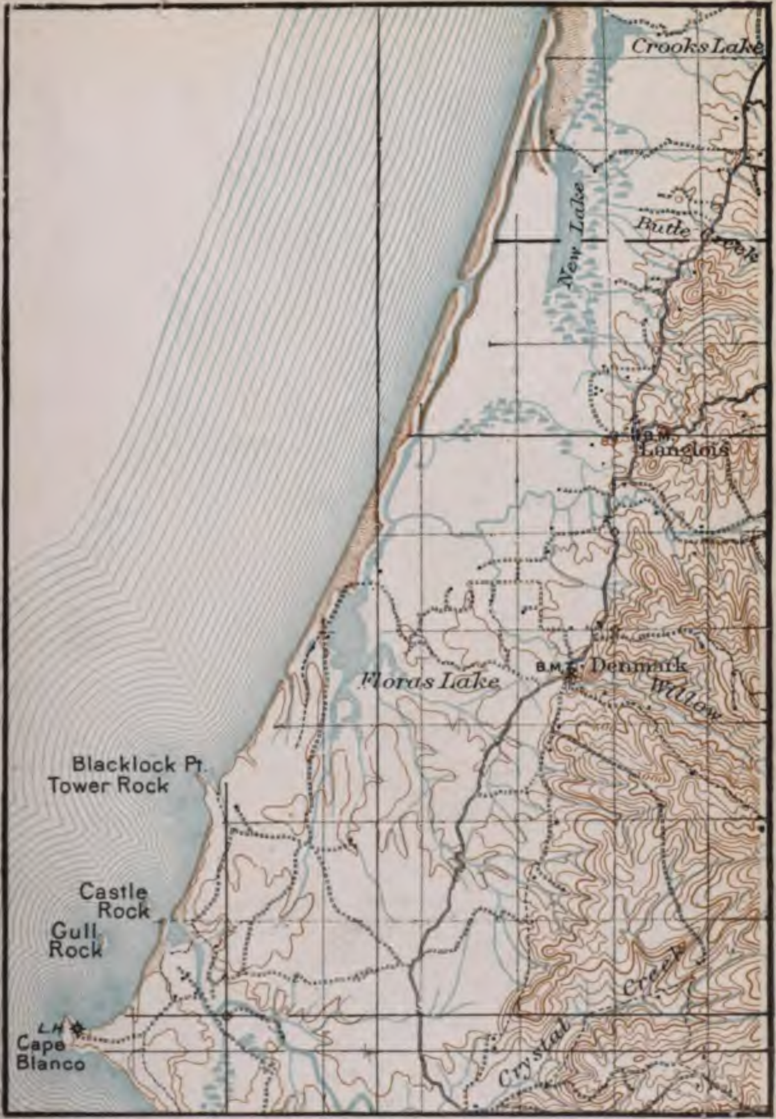
3. **Contours give some idea of the steepness of a slope.** The vertical space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise a given height on a gentle slope one must go farther than on a steep slope. Therefore contours are far apart on gentle slopes, and near together on steep ones.

Drainage. On the maps of the United States Geological Survey, water-courses are indicated by blue lines (Pl. I). If the streams flow all the year, the line is drawn unbroken; but if the channel is dry a part of the year, the blue line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed course under the ground is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue.

Culture. The works of man, such as roads, railroads, and towns, and also boundaries of townships, counties, and states, are printed in black.

Let us now apply these principles to Plate I. We notice at the outset that one inch on the map corresponds to about two miles, and that the contour interval is 100 feet.

We note at once that the contours are far apart at the left and close together at the right. This means that the surface is rougher at the east, and smoother at the west. The area at the east is higher



A narrow coastal plain in Oregon. Scale about 2 miles per inch. (Port Orford, Ore., Sheet, U. S. Geol. Surv.)

than that at the west, as the numbers on the contours show. The 500, 1,000, and 1,500-foot contours are heavier than the others, and are the only ones numbered. But small areas reach a height of 1,500 feet.

At the north, the first contour is nearly an inch from the coast. This shows that north of Floras Lake the land does not rise to the height of 100 feet for a distance of about two miles from the shore. South of Floras Lake, on the other hand, the 100-foot contour line is close to the shore, showing that there is a steep slope (cliff) more than 100 feet high along this part of the shore.

Cape Blanco has two contours, and is therefore more than 200 feet high. Gull Rock, Castle Rock, and Blacklock Point are more than 100 feet high. Few points reach a height of 200 feet, west of the rough land to the east. At the western border of the high land, there are steep slopes where six contours occur in the space of an eighth of an inch (¼ mile). This shows that the surface rises at least 500 feet in a quarter of a mile in some places, and this makes a steep slope. The principal wagon road of the region runs along the base of the steep slopes, while less important roads (indicated by dotted lines) branch from the main one.

Interior plains are often higher, and sometimes much higher, than coastal plains. A large part of the area between the Appalachian Mountains on the east, and the Rocky Mountains on the west, is a great interior plain. Here and there mountains, such as the Black Hills of South Dakota, and the Ouachita (pronounced Wash′-i-ta) Mountains of Arkansas and Oklahoma rise distinctly above the general level of this plain.

Extent and habitability. Plains are more extensive than plateaus or mountains, and most of the people of the earth live upon them. They are the chief places of human activity, partly because their climate is more favorable than that of higher regions, and partly because there is a greater proportion of land which is flat enough to be cultivated. Plains favor transportation and commerce, for (1) the building of roads, railways, and canals is much easier in plains than in higher and rougher regions; and (2) the streams of plains are more commonly navigable than those of mountains and plateaus. For these reasons, and also because many of the raw materials used in manufacturing are grown on plains, the larger part of the manufacturing of the world is there. It is noteworthy that the extensive plains most favored by climate and soil border the Atlantic Ocean, and, largely for this reason, these plains have been the theaters of the world's culture and trade.

In 1880, when the population of the United States was about 50,000,000,[1] about four-fifths of the people lived on lands less than 1,000 feet above the sea, and only about one-fiftieth lived above 2,000 feet.

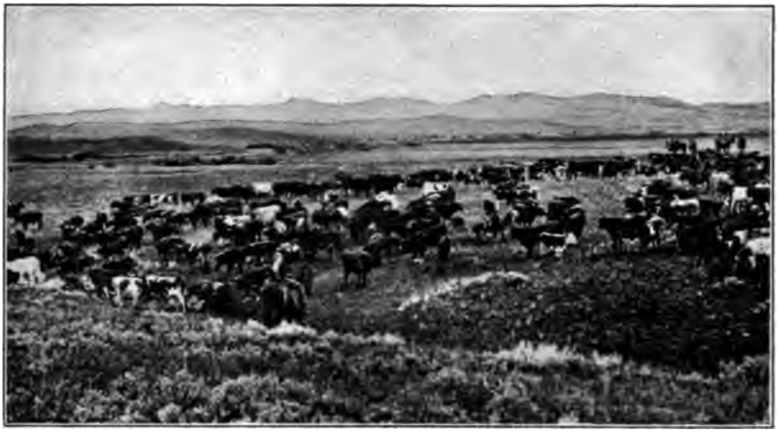


Fig. 11.—A plain in Wyoming. Mountains in the background.

Not all plains support an abundant population. Thus the northern plains of Eurasia and North America are too cold to be hospitable to varied industries, and their populations are likely to remain small.

Origin. Plains are formed in various ways. Some coastal plains are lands worn down from higher lands; others are parts of former continental shelves built up above the water by sediment laid down upon them; while still others represent former continental shelves, from which the sea-water has been drawn off. Some interior plains were once coastal plains. They are now inland because other land has been formed between them and the sea, so that they are no longer near the coast.

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[1] Later data on this point are not available.

Plateaus

Plateaus are tracts of land so situated as to appear high from at least one side, while they have, at the same time, considerable areas at or near their summit levels. Thus if a coastal plain rises gradually from the sea to a height of 200 feet, and then rises by a steep slope to another tract of level land which rises 200 feet higher (Fig. 12), the upper tract would be called a plateau, not so much because of its altitude above sea-level, as because of its distinct rise above the plain along one side of it. The Piedmont Plateau, which lies between the Appalachian Mountains and the Atlantic Coastal Plain of the United States, is not very high, but it is enough higher than the Coastal Plain to be distinctly set off from it. A large part of this plateau is, however, not so high as much of the great interior plain of the continent.

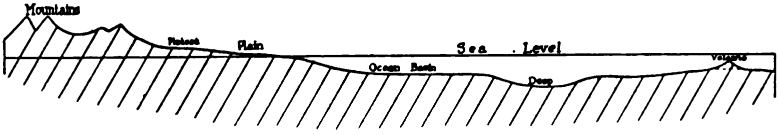


Fig. 12.—Diagram to illustrate the relations of mountain, plateau, plain, ocean basin, ocean deep, etc.

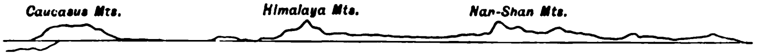


Fig. 13.—Section across Asia, showing plateau between the Himalayas and the Nan-Shan Mountains.

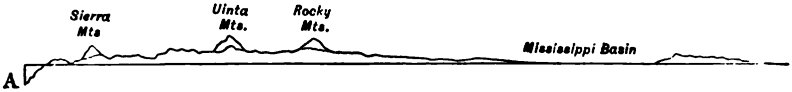


Fig. 14.—Section across North America, showing plateaus between the mountains in the western part.

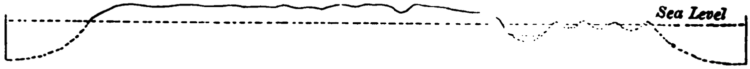


Fig. 15.—Section across Africa, latitude 10° S., showing a great plateau rising directly from the ocean. Vertical scale exaggerated about fifty times.

Plateaus often lie between mountains on the one hand and plains on the other, as in the case of the Piedmont Plateau. They often lie between mountains, as the plateaus of central Asia (Fig. 13), Mexico, and the western part of the United States (Fig. 14), and they sometimes rise directly from the sea, as in the case of Greenland and parts of Africa (Fig. 15). The total area of plateaus is great, though less than that of plains.

Except in low latitudes, high plateaus are too cold to be well adapted to agriculture, and their rainfall is often scanty. High plateaus are therefore less well fitted for human habitation than plains, and are usually sparsely settled. Low plateaus, on the other hand, may have a climate as favorable as that of plains. In low latitudes, even high plateaus may have a hospitable climate. The plateau of Mexico is an example.

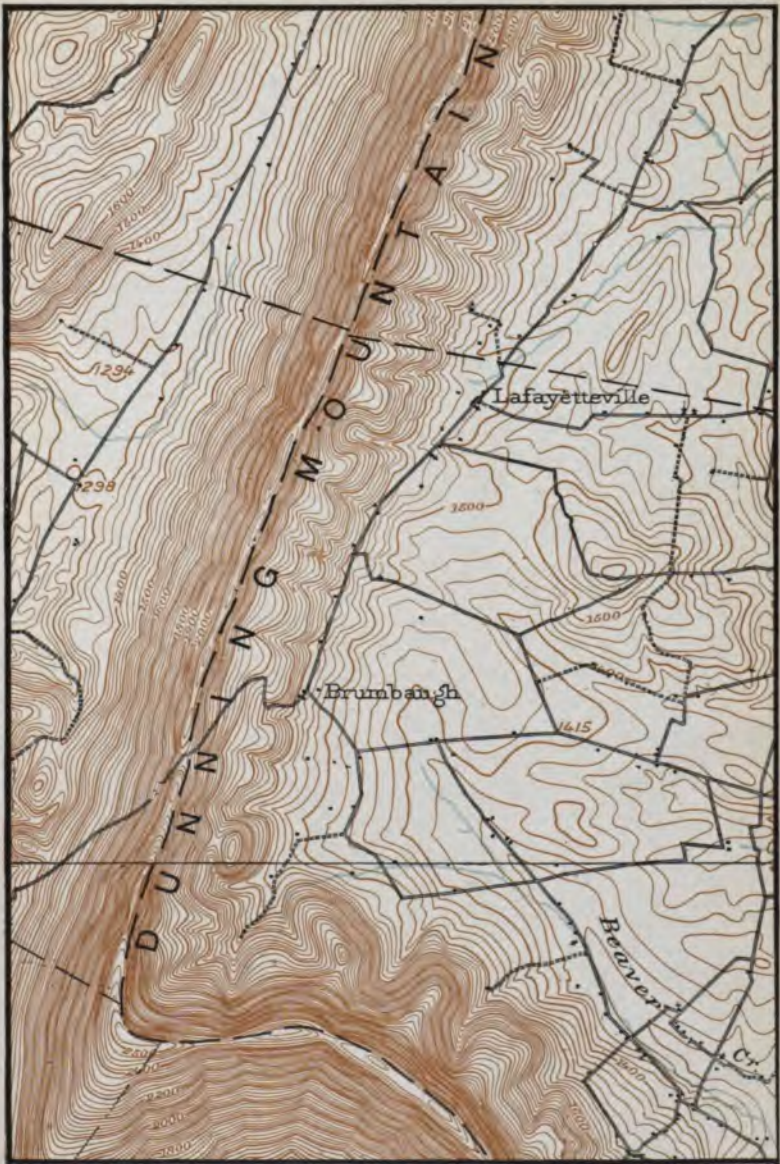
Origin. Plateaus attained their height in various ways. In some cases their surroundings probably sank away from them; in others, plateaus may have been elevated above their surroundings; while in still others, they have been built up by floods of lava. Such is the lava plateau of the northwestern part of the United States (Fig. 18).

Mountains

Mountains are *conspicuously high lands which have but slight summit areas.*

Though the tops of the loftiest mountains are between five and six miles above the level of the sea, most mountains have not half this height. The highest mountains tower above any plateaus, but many mountains are lower than the highest plateaus. Few, for instance, reach the height of the Plateau of Tibet, 15,000 to 16,000 feet.

Mountains are unlike plateaus of similar elevation in having little stretch of surface at the top. In the case of mountain *peaks*, this is shown by the name. A mountain *ridge* or *range* may be long, but its crest is usually narrow (Pl. II). The several ridges shown in Fig. 16 are examples. Numerous peaks or ranges are often associated, making a mountain *group* or a mountain *chain* (Fig. 16), but even in great mountain groups there is no great unbroken expanse of high land.



A good example of a narrow mountain ridge in Pennsylvania. The mountain is due to the great hardness of a layer of rock which comes to the surface along the **crest** of the mountain. The height of the mountain and the steepness of its slopes may be calculated from the map. It will be noticed that but one road crosses the mountain and this by a diagonal course. Scale *about 1 mile to* the inch. (Everett, Pa., Sheet, U. S. Geol. Surv.)

Where mountains rise abruptly to great heights above their surroundings, they are the most impressive and awe-inspiring features of the earth. In not a few cases they rise from low, warm plains to such heights that their summits are always covered with snow. Nowhere else are such extremes of climate found so close together.

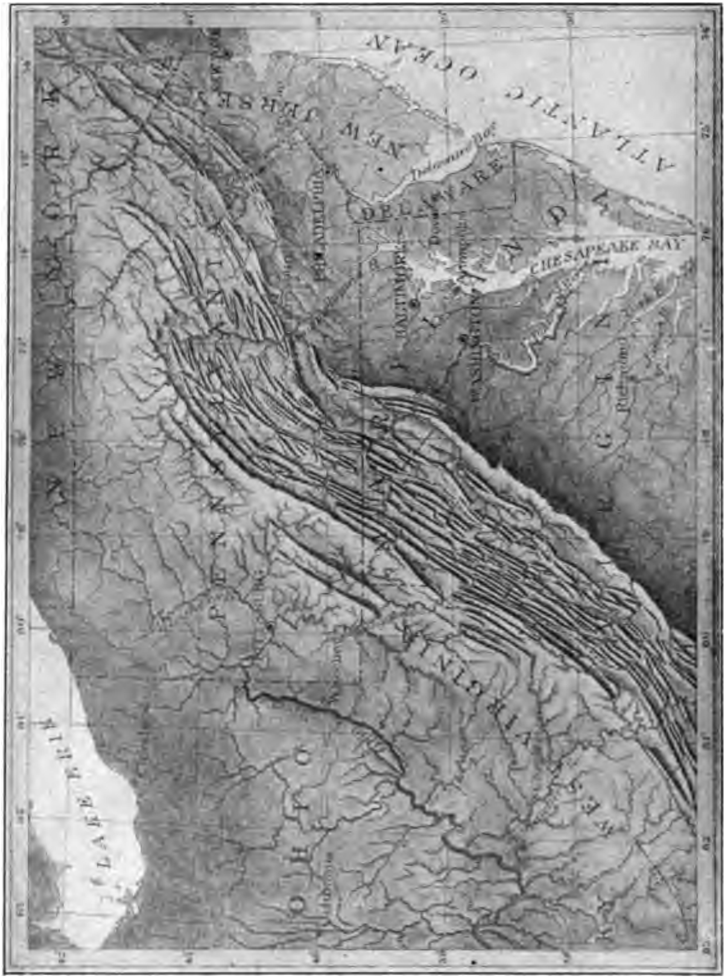


Fig. 16.—Relief-map of the Northern Appalachians and their surroundings. (U. S. Geol. Surv.)

Mountains are in contrast with plains and plateaus, and are the third of the three topographic types of the second order, as they appear on the lands of the earth.

In this grouping of mountains, only great groups or systems of mountains, such as the Appalachians, the Rockies, the Alps, the Caucasus, the Himalayas, or the Andes are considered. Since the term "mountain" is applied to any point or ridge of such steep slopes and so much above its surroundings as to be conspicuous, it follows that many elevations called mountains do not belong to the great physiographic type which is to be brought into contrast with plains and plateaus.

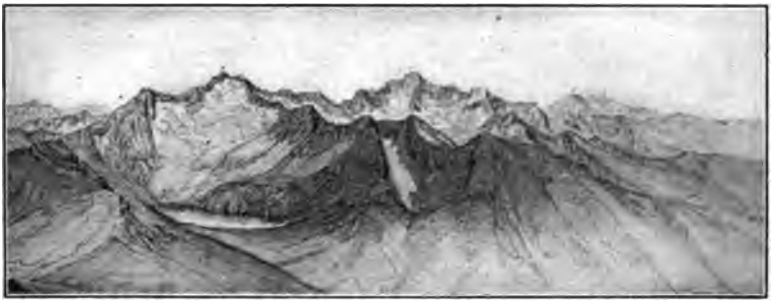


Fig. 17.—A portion of the Elk Mountains of Colorado. (Holmes, U. S. Geol. Surv.)

Origin. Mountains are made in many different ways, but the great systems of mountains are the result of warpings and foldings of the earth's crust. These will be studied later.

Habitability of mountains. Because of their low temperature, their steep slopes, and their scanty soil, mountains are ill-adapted to farming purposes. Since transportation in mountains is difficult, they are also ill-adapted to most industries which depend on the products of the soil. The valleys of mountain regions are, however, often fertile.

The most distinctive industry of the mountains is mining; yet many mountains have no ores or mineral matter of commercial value, while many ores, and many mineral substances which are not ores, are mined in plains and plateaus.

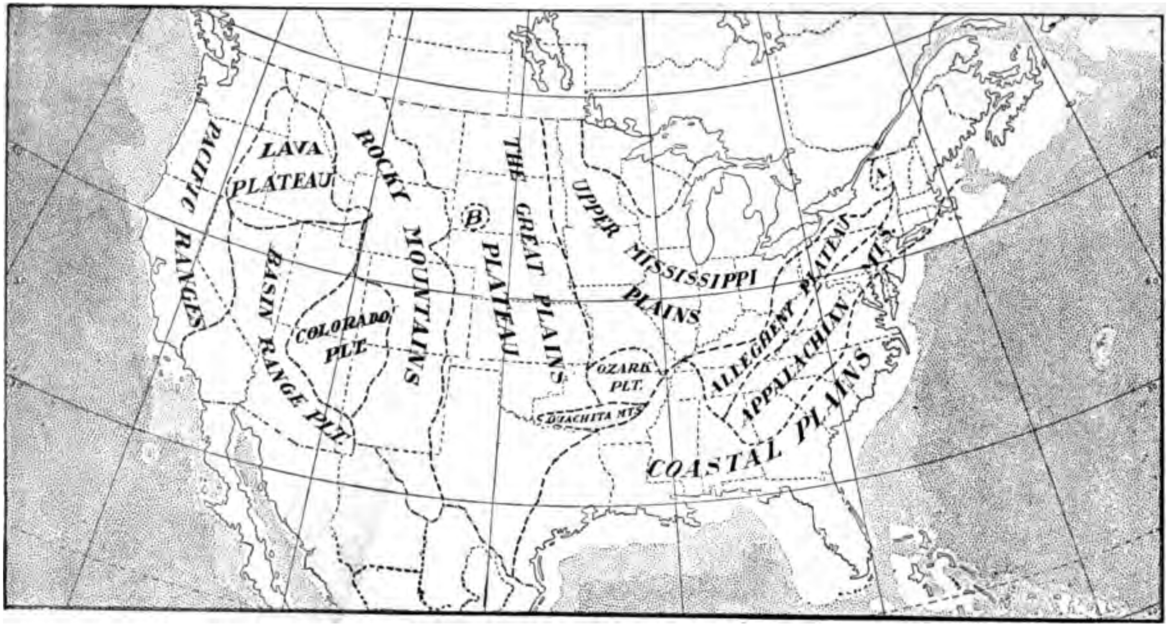


Fig. 18.—Map showing the principal physiographic subdivisions of the United States. (After Davis, with slight modifications.)

Mountains in history. Mountains have played an important part in history, partly because they are formidable barriers. They

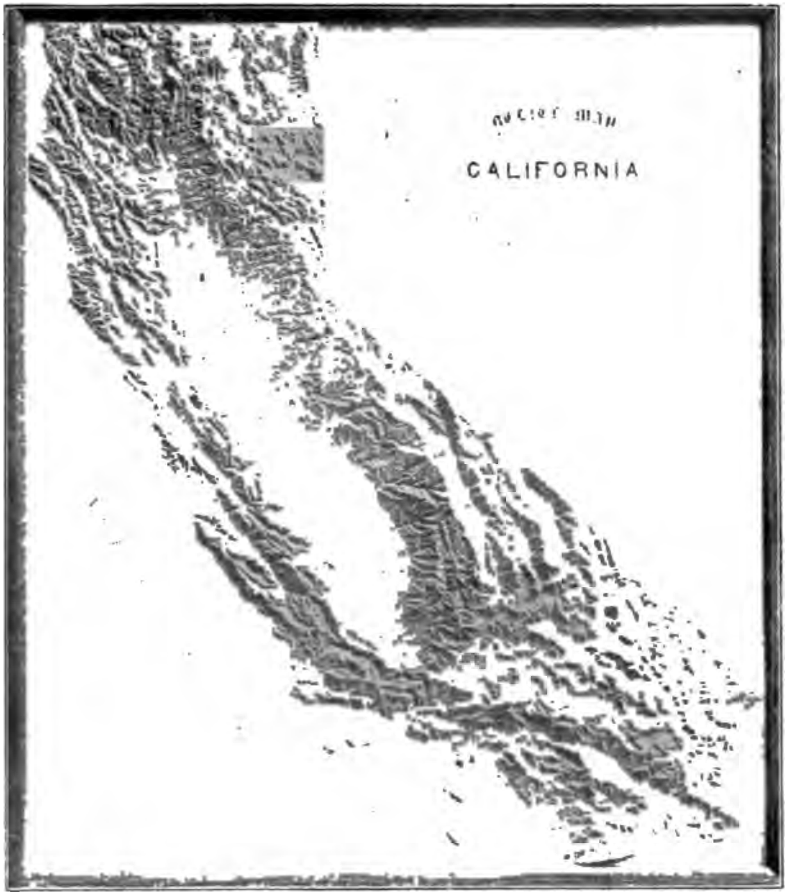


Fig. 19. Topographic map of California. The State is largely mountainous, but the central plain is conspicuous. (Photograph of model by Drake.

have sheltered their inhabitants from invasion, and they have frequently been the boundaries of political states. The mountains of western and southwestern Europe were one cause of the numerous small political divisions of those regions. Mountainous highlands have repeatedly given refuge to weak peoples, driven by their stronger enemies from the more desirable lowlands. The almost inaccessible mountain strongholds of Scotland, Wales, and parts of India enabled such peoples to maintain their independence for long periods. The Appalachian Mountains kept the English settlers on the eastern border of North America for nearly a century and a half, and influenced their life in many ways. Later, grave political dangers arose from the fact that the seaboard was separated from the valley of the Ohio by the same system of mountains.

Fig. 18 shows the distribution of the larger plains, plateaus, and mountains in the United States, and Fig. 19 shows the plains and mountains of California.

SUBORDINATE TOPOGRAPHIC FEATURES

The surfaces of plains and plateaus are often uneven, while the very name of mountain suggests ruggedness. Irregularities of surface consist of elevations, such as *ridges* and *hills*, above the general level, and of depressions, such as *valleys* and *basins* (depressions without outlets) below it. The elevations and the depressions are bordered by *slopes*, which, when steep, are called *cliffs*. Ridges, hills, valleys, basins, flats, cliffs, etc., affect mountains, plateaus, and plains; but they are usually more pronounced in mountains and plateaus than on plains. These minor unevennesses of surface are *topographic features of the third order*, and will be the subject of future study. The key to their history is found in the changes now taking place on the land, or in those which have taken place in recent times.

Changes now taking place on the land. Certain familiar changes are always taking place on the land. Some of them are brought about by the atmosphere, some by water, some by ice, some by the life of the earth, and some in other ways.

1. The air is nearly always in motion, and whenever it blows over a surface on which there is dust, some of the dust is picked up and carried to some other place. Grains of sand are blown about in the same way. The wind is therefore, one of the agents which

is changing the face of the land. The winds also carry the moisture of the air from place to place, and so influence the amount and the distribution of rain and snow.

2. Rain or snow falls almost everywhere on the land. A part of the rain which falls on the land runs off over the surface. When the snow of the land melts, much of the water follows the same course. The water which runs off over the land in streams is the most important agent modifying its surface, for it carries much mud, sand, and gravel from the land to the sea. Running water, therefore, tends to wear down the land.

The rain and snow water which sink beneath the surface also help to lower the land by dissolving mineral matter from the rocks. This matter is found in the water of all springs and wells.

3. Great bodies of ice, called *glaciers*, move slowly over the surface of the land in some places, especially on high mountains and on the cold lands near the poles. Glaciers make great changes in the valleys through which they move.

4. The waves of the sea and of the many lakes are continually modifying the position and the outlines of their shores. These changes are slight in short periods of time, but they have been very great in the course of the long ages of the earth's history.

The winds, rivers, glaciers, and waves are *agents of gradation.* They *degrade* (wear down) the surface at some points, and *aggrade* it (build it up) at others. In general, they degrade the land more than they aggrade it, for much of the material moved by them finds its resting-place in the sea.

5. Still another series of changes in the surface is brought about through the agency of life. Man, for example, grades down elevations, and he grades up depressions, as along railroads. He makes dams across rivers, converting portions of them into ponds; he raises and changes the banks of streams, shifting their natural courses and their natural work; he drains marshes and lakes, and more important than all else, he clears (removes the forests) and tills the land, thus preparing the way for the more effective action of wind and running water.

Plants and animals also affect the land in many ways. Thick *deposits of vegetable matter* are often found in marshes and shallow lakes. Again, plants have a protective effect on the surface. Little dust is blown from a forest, or even from a plain well covered with grass, and the water which runs down a hillside carries much less mud and sand from a slope covered with vegetation than from one freshly plowed.

6. Volcanoes also affect the land, sometimes giving rise to lofty mountains.

7. It is well known that the surface of the lithosphere seems to be rising in some places and sinking in others. This has also been true in the past, for beds of sediment, such as sand and clay, containing the shells of sea animals, are found at levels high above the sea. Great changes in the earth's surface have been brought about in this way.

Before studying the ways in which these various agencies affect the surface of the land, the materials on which they work must be briefly reviewed.

The Materials of the Land

The land is nearly everywhere covered with vegetation. In some places it is dense enough to form a thick mat over the surface, while in others it is meager, or even wanting. The surface well clothed with vegetation is the surface with which we are most familiar; but there are tracts of sand on which little or nothing grows, and cliffs where the rock is bare, save for scattered patches of moss or lichen. In the polar regions, and on lofty mountains also, the land is often covered by thick beds of snow on which there is no vegetation of the sorts with which we are familiar.

Mantle rock. Beneath the vegetation, there is, in most regions, a layer of loose material, composed of clay, loam, sand, gravel, etc., of variable thickness. This layer of earthy matter may be a few inches in thickness, or it may be scores or even hundreds of feet deep. This loose material is *mantle rock*, because it covers and conceals the solid rock which lies below (Fig. 20). It is also known by other names, among which *rock waste* is in common use.

The uppermost portion of the mantle rock is commonly called *soil*. In color, the soil may be black, gray, brown, or even dull red or yellow. It may be either clayey and compact, or sandy and porous. In most cases it is made up largely of small particles of mineral or rock. If a piece of any common sort of rock be put into a mortar and ground to powder, this powder will somewhat resemble soil. In general we cannot recognize the kinds of rock from which the mineral particles of the soil came, for they are usually very small. In addition to the mineral matter, the soil contains more or less partly decayed vegetable (*organic*) matter. Bits of roots may often be seen in it, and sometimes fragments of decayed leaves.

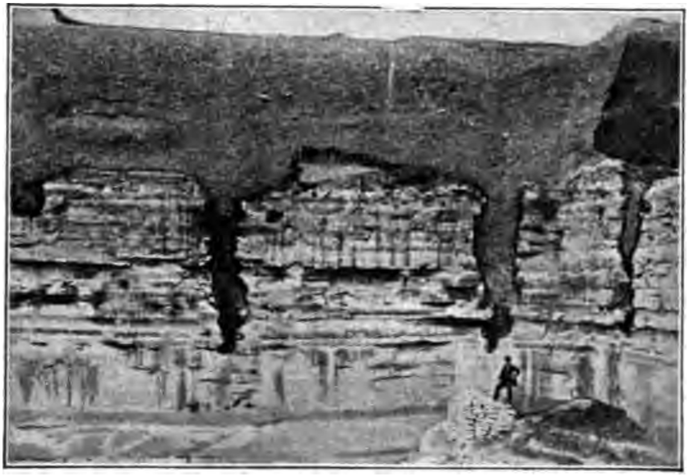


Fig. 20.—Figure showing the irregular contact of solid rock below, with soil, subsoil, etc , above. The rock has decayed so that the subsoil extends down irregularly into it. (Robin.)

Both the mineral and the organic matter are necessary parts of a good soil, but their proportions vary greatly. The mineral matter is usually far in excess of the organic, but in bogs and marshes which have been drained, the organic matter is often the more abundant. That part of the mantle rock which is properly called soil ranges from a few inches to a few feet in thickness.

The distribution and prosperity of the people of the earth often bear a very direct relation to the fertility of the soil. The fertile blue-grass region of Kentucky was the first extensive area to be settled in the Ohio Valley; its inhabitants have always been progressive and well-to-do. The hilly land to the east was slowly occupied by a spare population, condemned by a less fertile soil to relative poverty.

Where the mantle rock is thicker than the soil, the soil grades down into earthy matter of somewhat different composition, known as *subsoil.* Between the two there is no distinct separation, but the subsoil is often more compact than the soil, and its color is often different. Like the soil, it contains both mineral and organic matter, though the latter is less abundant than in the soil. Only the larger roots penetrate the subsoil in great numbers. The thickness of the subsoil is often much greater than that of the soil, but on the other hand, it is sometimes absent altogether.

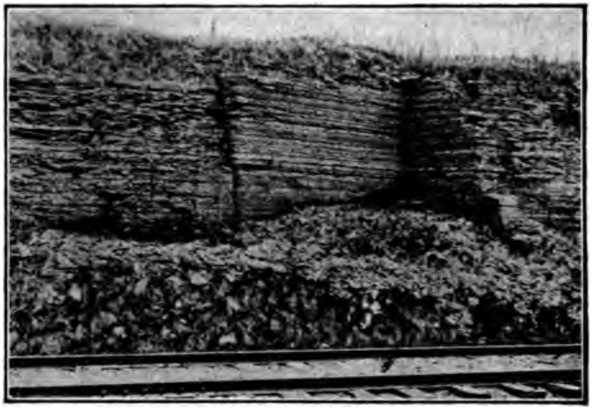


Fig. 21.—Stratified rock, Trenton Limestone, Fort Snelling, Minn. (Calvin.)

Beneath the subsoil is *rock.* When we speak of rock, we do not always mean solid rock, for sand, gravel, clay, etc., in large quantities, are included under this term. As commonly used, however, the term "rock" means solid rock, and beneath the loose materials of the surface, the larger part of the earth down to the lowest accessible depths, and doubtless far beyond, is solid rock. It is probable, indeed, that the earth is solid to the core.

Classes of solid rock. The solid rocks of the earth are of many kinds. They differ from one another in color, in strength, in texture, in composition, in origin, etc., but for our purpose the common rocks may be grouped into two great classes; namely, those which are in layers, called *stratified rocks* (Fig. 21); and those which are not in layers, or *unstratified rocks* (Fig. 22).

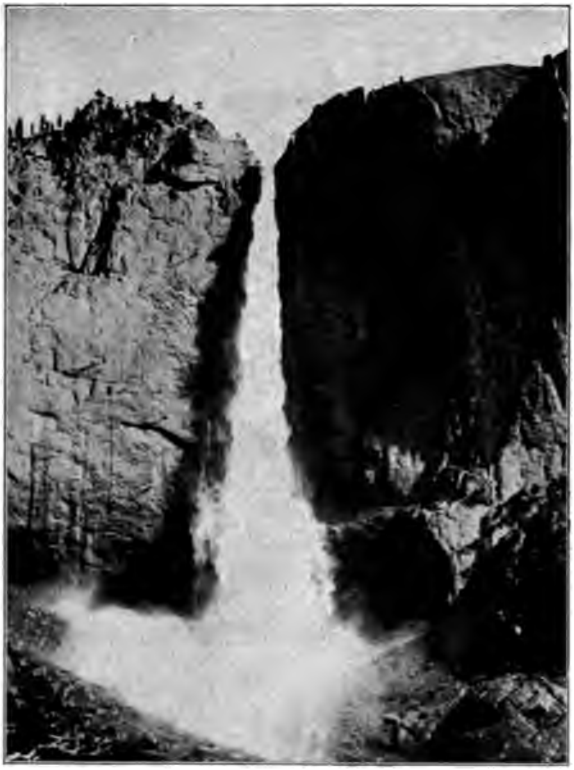


Fig. 22.—Massive, or unstratified, rock; the Upper Yosemite Falls. Compare the structure of the rock with that shown in Fig 21.

CHAPTER II

THE WORK OF THE ATMOSPHERE

The atmosphere is nearly everywhere in contact with the land, and it penetrates the soil and the rock beneath to the depth of hundreds and thousands of feet. It affects the land in many ways, but only a few of the changes which it brings about will be noticed here.

1. MECHANICAL WORK.— THE WORK OF THE WIND

Dust

All the small particles of solid matter in the air are called *dust*. On windy days, in dry regions, the dust in the air may be seen. It is present, even when the air seems perfectly still, and it may be seen by letting light into a dark room through a narrow crack, or a small hole. In the light thus entering, countless dust motes are visible. Dust is found in the air over even the loftiest mountains. It is carried far from its sources, for it sometimes falls on the decks of vessels far out at sea.

The presence of dust in the atmosphere may be shown in another way. If a quantity of rain-water, which has just fallen, be evaporated, a little sediment remains. This sediment is the dust brought down by the falling drops. If freshly fallen snow is melted and evaporated, there is a slight residue of dust. This is the case even if the snow be taken from mountain tops, or from such a place as Greenland, far from the cultivated lands and streets which furnish much of the dust of thickly settled regions. Since all rains and snows bring down dust, dust must be present everywhere in the atmosphere.

Sources. Much of the dust in the air is made of fine particles of earthy matter blown up from streets, plowed fields, and surfaces not well covered with vegetation. Where the surface is very dry and the wind strong, "clouds" or "whirls" of dust are sometimes swept up by the rising currents of air, and may be seen for miles. This is true in deserts, especially.

The solid particles of smoke (soot), the pollen of flowers, the spores of plants which, like the puff-ball, do not blossom, are also abundant in the atmosphere. These various sorts of dust are picked up and blown about by the wind.

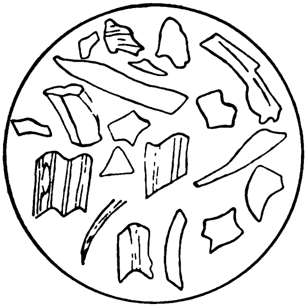


Fig. 23.—Particles of volcanic dust greatly magnified.

Explosive volcanoes often send great quantities of rock matter, broken up into fine particles, high into the air. This is *volcanic dust*. It is also called *volcanic "ash,"* but this name is not a good one, because the dust is not the product of burning. It is lava blown into tiny bits (Fig. 23).

In August, 1883, a violent volcanic eruption took place on the Island of Krakatoa, between Java and Sumatra, and half the island was blown away. At the same time, enormous quantities of dust were shot up into the air to the height of several miles, and then blown great distances before they fell. Dust in the air affects the sunlight coming through it. When the sun is low, as at sunset, the dust affects the light so as to give color to the western sky. After the eruption, the bright sunsets occurred at first near Krakatoa, and then farther and farther away. In this way it was estimated that the volcanic dust was carried completely around the earth, and that it took only about fifteen days to make the circuit. It has been estimated that some of the dust was still in the air three years after the eruption, and that a portion of it went several times around the earth before settling. It is probable that the dust from this single volcanic eruption found its way to nearly all parts of the earth. This shows how long dust may be held in the air, and how far it may be carried.

Dust in the lower part of the air is not usually held so long or carried so far, partly because the winds are less strong, and partly because the dust is blown against all sorts of obstacles, such as hills, trees, etc., which cause it to lodge.

A little dust reaches the earth from space outside the earth. "Shooting stars" are small bits of solid matter which enter the atmosphere from outside space. In falling toward the earth, they become glowing hot, because of friction with the air through which they pass. Before they reach the bottom of the air, they are broken into tiny particles of dust. A great deal of dust reaches the earth this way every day. This dust is sometimes called *cosmic*, or *meteoric dust.* Some solid bodies coming into the air from outside space are so large that they are not altogether broken up into dust in the atmosphere. When pieces of larger size reach the land, they are called *meteorites.*

How held in the air. The particles of dust are very much heavier than the air, and gravity tends to bring them down. In spite of this, the particles remain suspended in the air (1) because they are so small that they do not fall readily; and (2) because there are many upward currents in the air which overcome the effect of gravity, and carry the particles upward. As a matter of fact, the dust of the atmosphere is always settling somewhere, and the supply is being constantly renewed.

Distribution. Since the wind is always blowing, it is probable that dust is carried to all parts of the earth. Indeed, it might almost be said that every square mile of the earth's surface may have received dust from every square mile of dry land. The dust which lodges on land may be picked up and blown about again and again, but that which falls into the ocean, or into other bodies of water, is safe from further disturbance by the wind.

Deposits of dust. From the flood plains of such rivers as the Missouri, clouds of dust are swept up and out over the neighboring highlands, whenever the surface of the flood plain is dry and the wind strong. The deposits of such dust on the highlands in any one year are not great, but in the course of centuries they may become very thick.

In parts of China, and Europe, and over extensive areas in the Mississippi basin, there is a layer of peculiar earthy material, a large part of which was deposited by the wind, as dust is now being

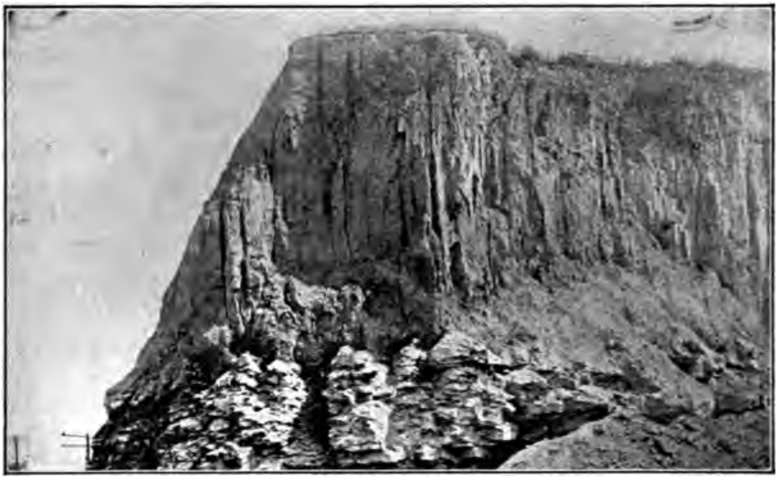


Fig. 24.—Bluff of loess at Kansas City. (Mo. Geol. Surv.)

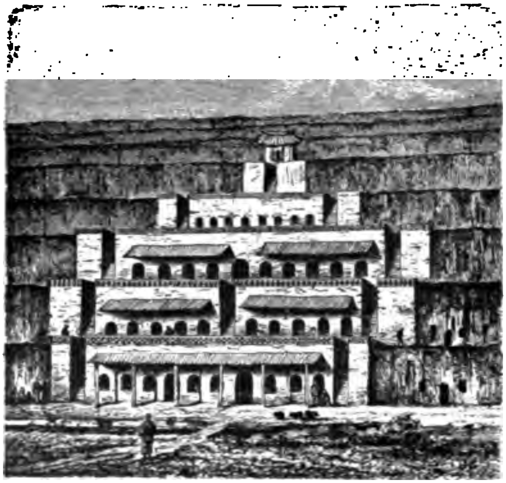


Fig 25.—Façade of a group of buildings in a bluff of loess, Province of Shansi, China. (Richthofen.)

deposited on the bluffs of the Missouri and some other rivers. This material is known as *loess*, the particles of which are smaller than sand grains, but larger than particles of clay. In China, the loess is said to be several hundred feet thick in some places, but in the United States it is rarely more than 30 to 50 feet thick. It makes a most fertile soil in regions where the climate is not too dry.

Steep slopes or cliffs are sometimes formed in the loess after its deposition. Such slopes often stand for a long time, even when they are nearly vertical (Fig. 24). In parts of China, the people have excavated houses in successive tiers in these steep slopes (Fig. 25).

Dust has, in the course of ages, buried cities in which many people once lived. Nineveh is supposed to have been buried in this way.

Deposits of volcanic dust. The volcanic dust which falls close about the volcanoes is not the work of the wind chiefly, though the wind often blows volcanic dust great distances, in such quantities as to make thick beds. In some parts of Nebraska, for example, there are deposits of volcanic dust 30 feet thick, hundreds of miles from the nearest known volcano.

Since dust is being blown from the land to the sea all the time, and since the sea is not making an equal return of material to the land, the wind tends to lower the land and to build up the sea bottom.

Sand

Sources. Even gentle winds pick up and carry dust; strong ones pick up and carry grains of sand, and even very small pebbles. Like dust, sand is blown about only when it is dry. Abundant sand is found along many shores of seas and lakes, on the bottoms of some river valleys, in desert regions, and in certain other situations. In most of these places, the sand is dry at times, and in some of them it is dry most of the time.

Lodgment of wind-blown sand. Sand is not often carried up so high as dust, nor do the grains remain so long in the air. Because they are larger, they fall more rapidly (why?) when the wind is checked. Because they are carried chiefly in the lower part of the atmosphere, they are likely to be stopped by obstacles of all sorts on the surface. Thus every tree, log, stump, building, and fence, and every mound and hill against which sand is blown, is likely to cause some of it to lodge, just as it may cause drifting snow to lodge. It follows that sand, instead of being scattered more or less evenly over the surface, as dust is, is often left in mounds and ridges, resembling snow drifts.

Dunes. Mounds and ridges of wind-blown sand are *dunes*. They may begin their growth about almost anything on the surface which blocks the way (Fig. 26). After being started, a dune becomes an obstacle to blowing sand, and as more sand lodges against it, the dune grows. Dunes sometimes reach a height of several hundred feet, but small dunes are much more usual. Figs. 27–29, show dunes of various forms.

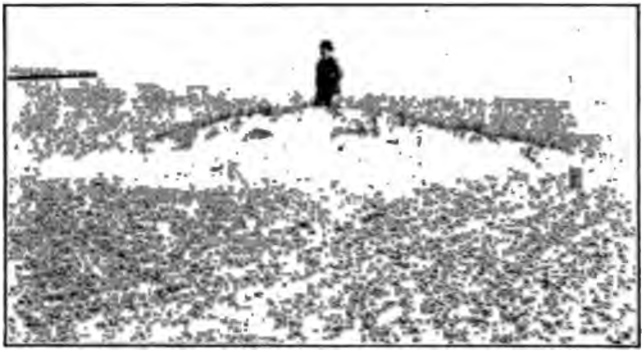


Fig. 26 — The beginning of a dune. Sand has lodged about the tufts of vegetation Shore of Lake Michigan, south of Chicago. (Cowles.)

Distribution of dunes. Dunes are found mostly near the sources of abundant dry sand. They are common along much of the Atlantic coast of the United States, where the sand is washed up on the beach by the waves. When it dries, it may become the prey of the wind. Winds from the west blow this sand into the sea; those from other directions, but especially from the east, drift it up onto the land. Dunes abound along the eastern side of Lake Michigan, and some of them are very large; but there are few on the west shore. This is because the prevailing winds are from the west. The sand

PLATE III

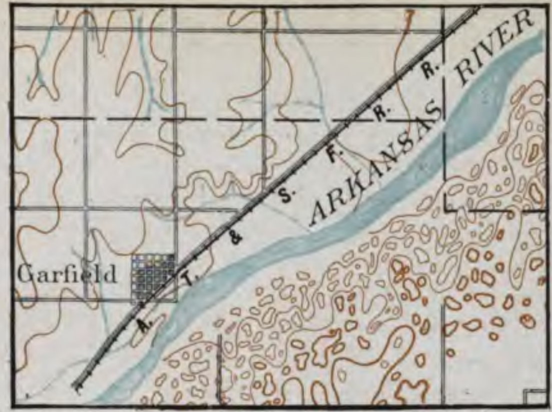


FIG. 1.—Dunes along a river. The dunes have the shape of mounds. Scale about 2 miles per inch. (U. S. Geol. Surv.)

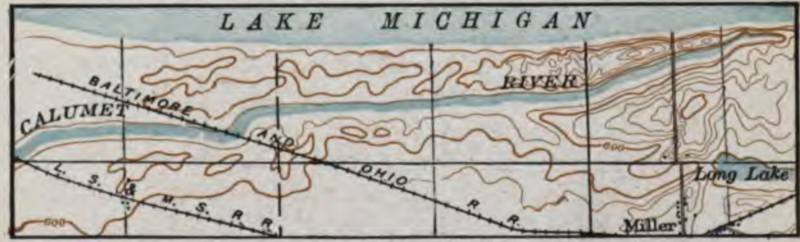


FIG. 2.—Dunes at the south end of Lake Michigan. All the elevations shown on the map are dunes, which are ridge-like rather than mound-like. Scale about 1 mile per inch. Contour interval, 10 ft. (U. S. Geol. Surv.)

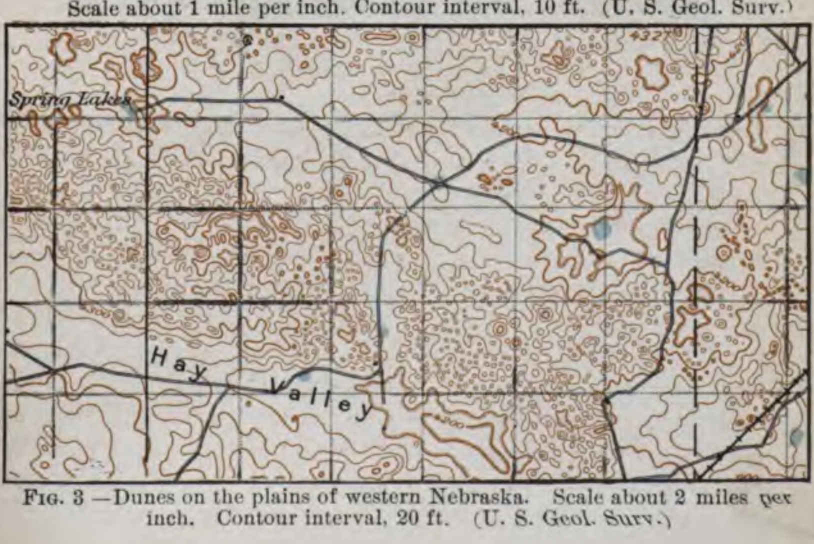


FIG. 3.—Dunes on the plains of western Nebraska. Scale about 2 miles per inch. Contour interval, 20 ft. (U. S. Geol. Surv.)

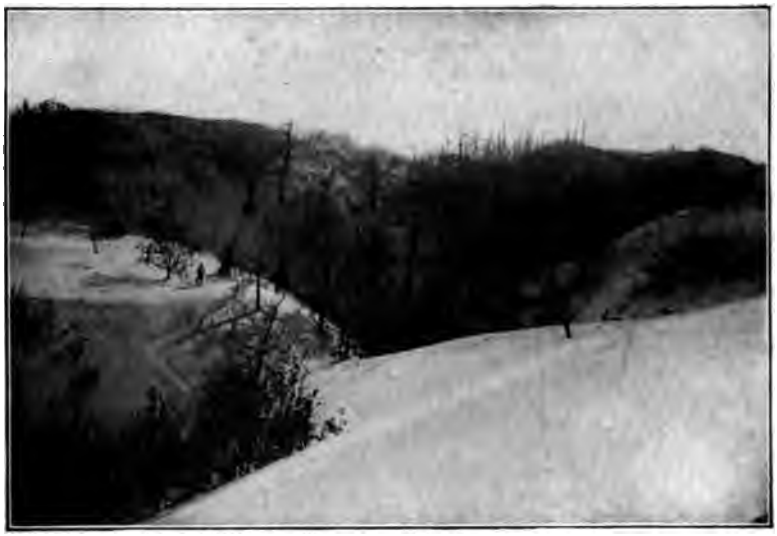


Fig. 27.—A group of dunes at the head of Lake Michigan. (Cowles.)

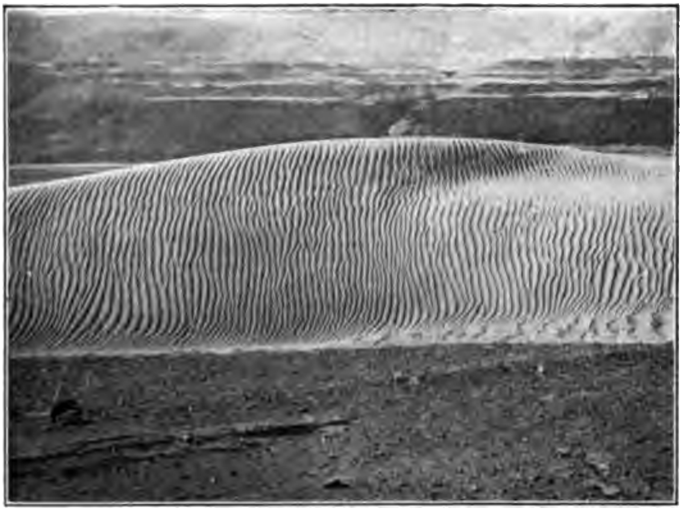


Fig. 28.—Wind ripples on the surface of a dune. Western United States. (U. S. Geol. Surv.)

of the east (leeward) shore is blown up on the land, while that on the west shore is generally blown into the lake. Dunes are also more frequent on the leeward than on the windward side of river valleys. Thus where westerly winds prevail, as in most of the United States, most of the dunes along valleys are on their east sides. Dunes abound over thousands of square miles of land in the semi-arid parts of the Great Plains, as in western Nebraska and western Kansas. Dunes of great size occur also in the central part of Wyoming, and they reach their greatest development in still drier regions, such as the Sahara. In some places, dunes are the most conspicuous feature of the landscape. They are, on the whole, more common on plains and low plateaus, than in mountains.

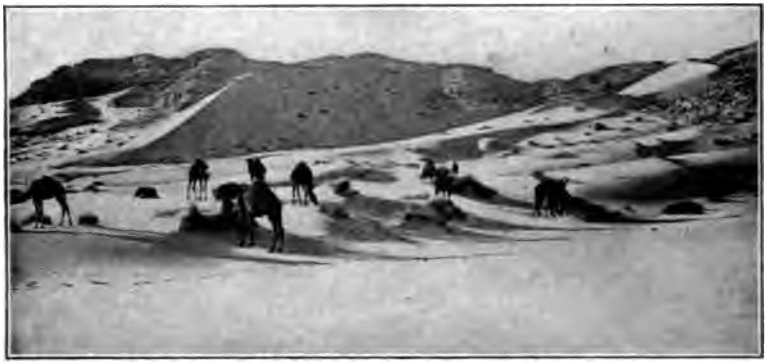


Fig. 29.—Desert dunes near Biskra, Algeria. (Leroux.)

Associated with the dunes there are often depressions, some of which have no outlets. Some of these depressions were scooped out by the wind, and some of them were shut in by the building up of sand drifts about them.

Destructiveness of wind-blown sand. The piling up of sand into dunes sometimes does great damage. Farm lands, especially near sea coasts, have been covered in this way, and forests of large trees have been buried (Fig. 27). Some trees make heroic efforts to maintain their life against the burying sands, by sending out roots from their branches, after the trunks below the branches have been buried. In this way, they may survive until they are covered almost to their tops. Sometimes the sand buries buildings, and occasionally it causes much trouble along railways, as shown in Fig. 30. Many caravans have been destroyed in the African desert by sand storms.

Migration of dunes. Sand is being blown from the windward side of a dune and dropped on the leeward side, much of the time.

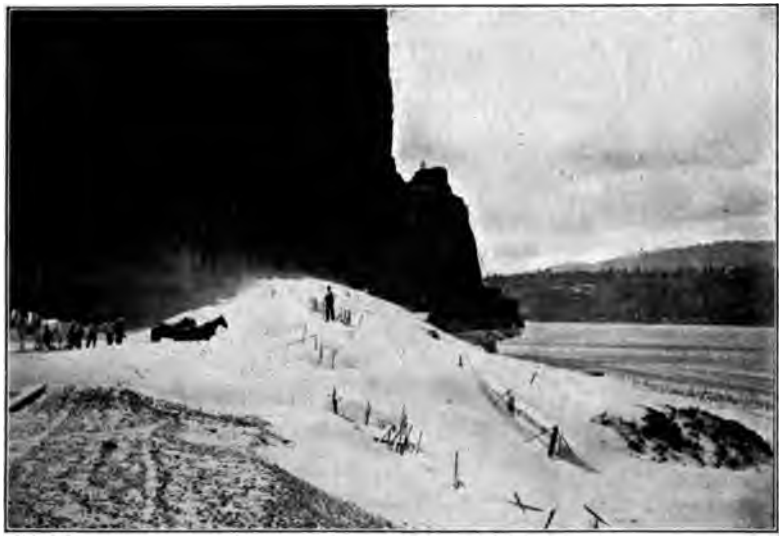


Fig. 30.—Sand drifted over a railway. One rail shows at the left-hand side. Rowena, Wash. (U. S. Dept. of Agr.)

This continued shifting of sand to the leeward side, results in a slow migration of the dune in the direction of the prevailing winds.

We may get some idea of the extent to which dunes migrate, in various ways. When dunes which buried forests move on, the trees which were covered and killed, may be seen again, as shown in Fig. 31. The onward movement of the dune sand may uncover other things also. At one locality on the coast of North Carolina, a sand area was used for a cemetery. The wind has now blown away enough sand to leave the bones of the buried bodies on the surface.

Buildings buried by dunes are sometimes brought to light again after the dune has moved on.

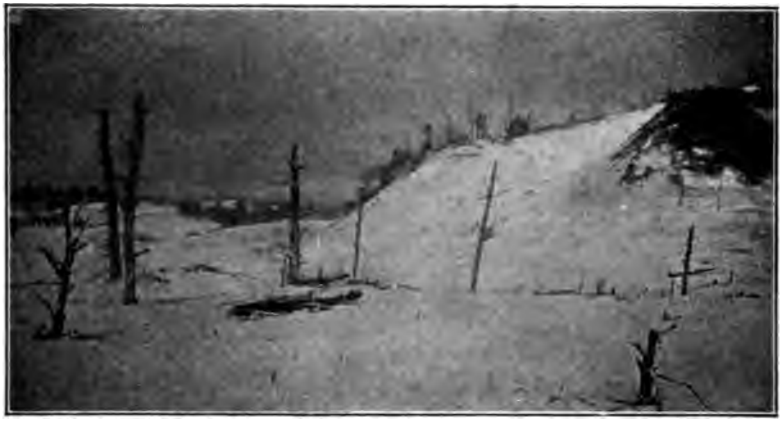


Fig. 31.—A resurrected forest. After burying and killing the forest, the sand has blown away, exposing the dead trees. (Myers.)

So disastrous is the migration of dunes along some coasts, that steps are taken to prevent it. If a dune is covered with vegetation, its position is not likely to be changed so long as the plants remain, for the plants hold down the sand. Trees, shrubs, etc., which will grow in sand are sometimes planted on dunes, as soon as they are

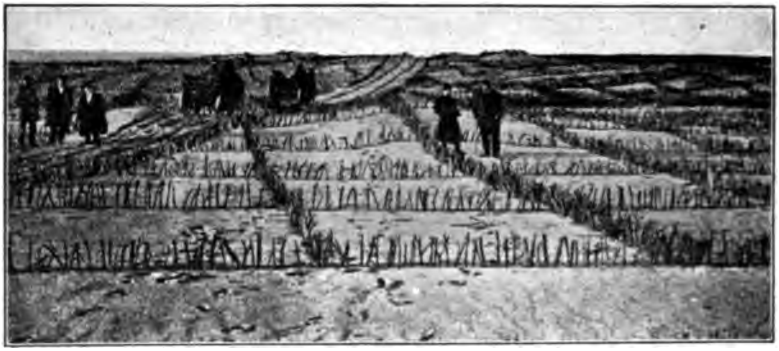


Fig. 32.—Dune sand held by brush fences on Kurische Nehrung.

formed, to prevent further drifting (Fig 32). This is done at various points along the western coast of Europe, where land is valuable, and it has been done to some extent in our own country, as at San Francisco, where the westerly winds tend to drift sand in from the shore. Fig. 33 shows the effect of a clump of trees in holding sand. All the dune except that part held by the roots of the trees has been blown away.

Eolian (wind-blown) sand is not always heaped up into dunes. It is sometimes spread somewhat evenly over the surface where it lodges. Eolian sand is therefore more widespread than dunes are.

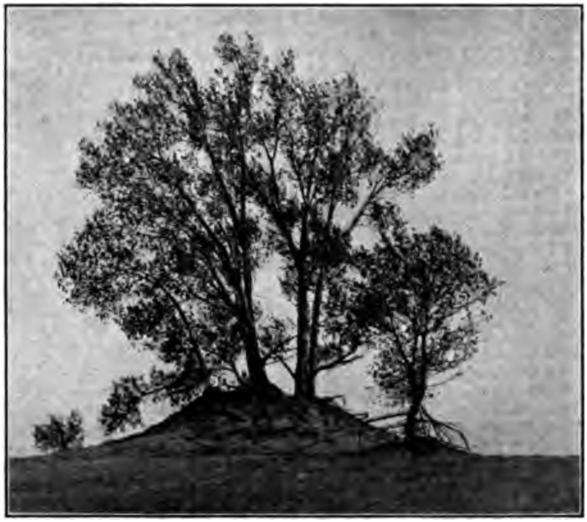


Fig. 33.—The remnant of a dune held by roots. The surrounding sand not so held has been blown away. Head of Lake Michigan. (Cowles.)

The surface of wind-blown sand is often marked by ripple-marks (Fig. 28), very like the ripple-marks on the surface of sand deposited beneath water.

Gradational effects. Much sand is blown from the land into the sea; but the waves wash some of it up on the beach again. While the one process reduces the volume of the land, and the other increases it, the relative importance of these two is not known.

The amount of dust and sand shifted about on the land, or from the land to the sea, by the wind, is very great. It has been estimated that in violent dust-storms, the amount of dust and sand in the air may amount to 126,000 tons per cubic mile of air. The average amount is probably but a very small fraction of one per cent of this amount.

Abrasion by the wind. Sand blown against a surface of rock has the effect of a sand-blast, and wears away the rock. If some parts of the surface against which sand is driven are harder than others, the softer parts are worn the more rapidly. Where abundant sand is driven by the wind, projecting rocks are often carved into fantastic forms (Figs. 34 and 35). Abrasion by wind-driven sand is of little consequence in a plain country where the climate is moist, and where bare rock is rarely exposed; but it is of much consequence in arid and semi-arid regions where the topography is rough, and where hills and points of bare rock are numerous. Wind-driven *dust wears the surface of rock* much less than sand does.

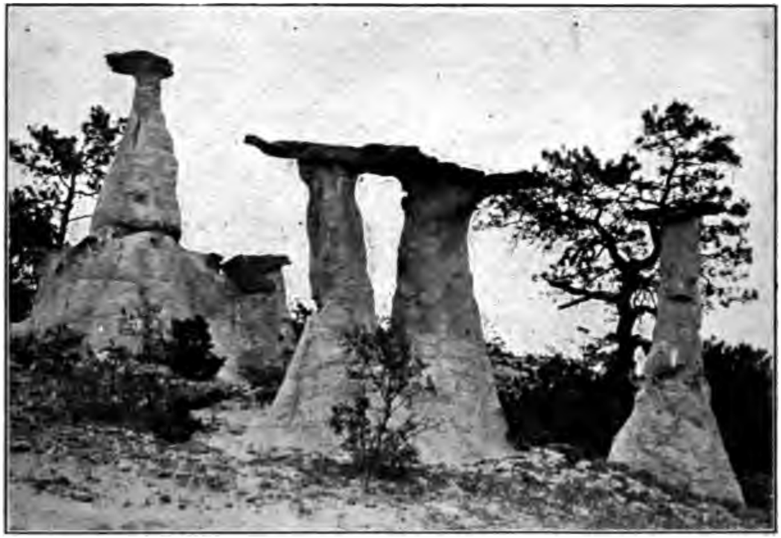


Fig. 34.—Erosion columns in Monument Park, Colo.; partly the product of wind erosion. (Fairbanks.)

2. THE CHEMICAL WORK OF THE AIR

The chemical changes produced by the air on soil and rocks cannot be understood without some knowledge of chemistry; but certain familiar facts will help us to see the general nature of these changes.

When a piece of iron or steel, such as a knife-blade, is left in the moist air, it rusts. In the process of rusting, both oxygen from the air and water have entered into combination with the iron, and the iron rust contains all three substances, united into one. The iron rust scales off, and a knife-blade will soon be "eaten away" if the rusting is allowed to go on.

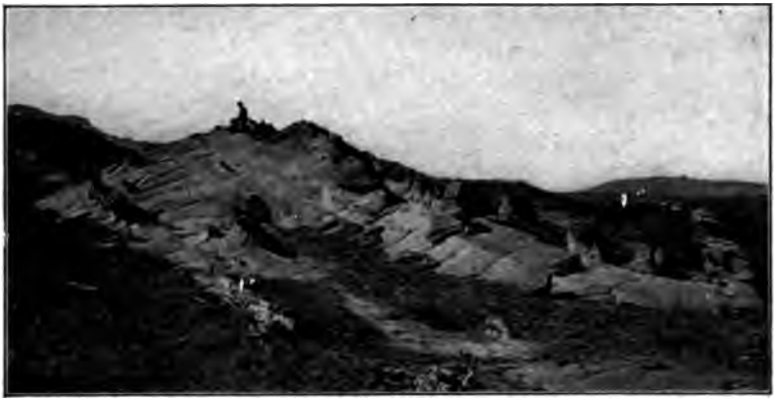


Fig. 35.—Rock carved by wind-blown sand. Near Klondike, Wyoming.

Similar changes take place in some rocks. Iron is present in many of them, and this iron rusts much as the knife-blade does. Other parts of the atmosphere also help to change some of the minerals of the common rocks, and in most cases the rocks crumble in consequence.

Weathering. All changes of the surface rocks which make them crumble are parts of the general process of *weathering*, which includes most of the natural processes by which rock at or near the surface is made to change its form or color, or to lose its solidity.

The processes of weathering are very important. Much of the soil and subsoil (mantle rock) of the earth have been made by them, and the weathering of the rock prepares it for ready transportation by wind and water.

3. CHANGES BROUGHT ABOUT UNDER THE INFLUENCE OF THE AIR

The surface of the land is subject to great changes of temperature, which are of importance in various ways.

Freezing and thawing. In many regions where the surface is well covered with soil, it freezes in winter; that is, the water in it freezes, and the soil becomes solid. While frozen it cannot be blown or washed away. In low temperatures, too, the moisture which falls from the atmosphere falls as snow instead of rain, and does not have the same effect on the land as rain. When the snow melts, the water runs over the surface much as rain-water would; but if the soil beneath the melted snow is frozen, the effect of the running water is slight.

Where the soil is thin, the waters which sink may freeze in the cracks of the rocks beneath. Since water expands about one-tenth on freezing, the ice which forms in the cracks acts like a wedge, prying the rock apart. The effect of expansion during freezing is illustrated by the breaking of a bottle in which water is allowed to freeze. This process of rock-breaking is most important where there is abundant moisture, and where the changes of temperature above and below the freezing-point of water are frequent. This is the case in middle latitudes, or in altitudes which have the temperatures of middle latitudes.

Expansion and contraction of rock: rock-breaking. When solid rock has no covering of loose material, as is often the case on steep slopes, it is heated by day and cooled by night. At high altitudes, and especially on slopes and cliffs exposed to the noonday sun, the daily changes of temperature of the surface of the rock are great. In such places, the surface of the rock may become very hot while the sun shines. Heat expands rock, and as the heated part expands, it is likely to scale off from the part beneath (Figs. 36 and 37). As *the sun goes* down, the surface cools and contracts. The outermost

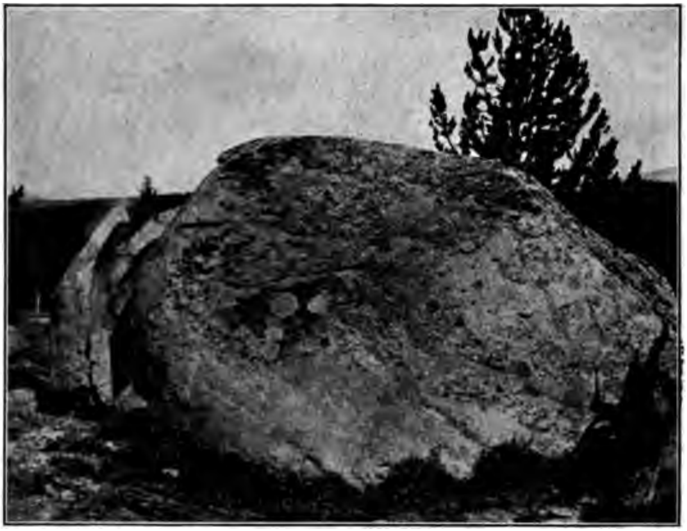


Fig. 36.—The shelling off of a granite bowlder near East Tensleep Lake, Wyoming. (Hole.)

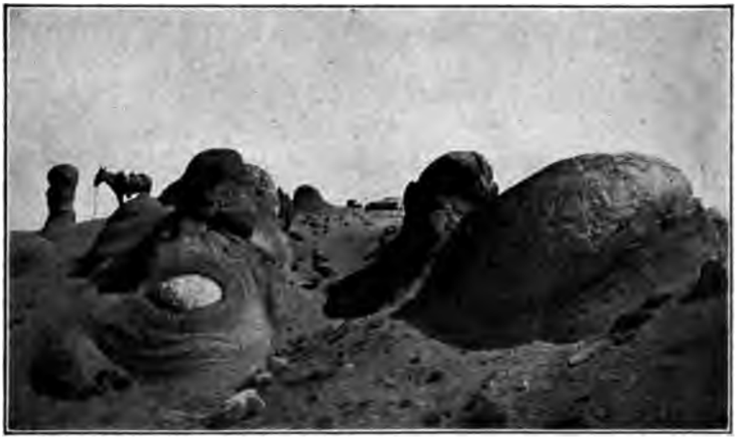


Fig. 37.—A peculiar form of shelling off, or exfoliation, in granite; California (U. S. Geol. Surv.)

film of rock cools first and most, and tends to break. The breaking of cool glass by touching it with hot water, or of hot glass by touching it with cold water, involves the same principle.

The breaking of rock by heating and cooling, even when ice is not formed, is very common. On hot days in summer, the blocks of cement in cement walks sometimes expand so much that they arch up where they meet (Fig. 38). This results in the breaking of the cement. The heat of the sun sometimes so expands the rock in the floor of a rock quarry, that it is similarly bowed up and broken. *This has been seen* more than once in the limestone quarries about

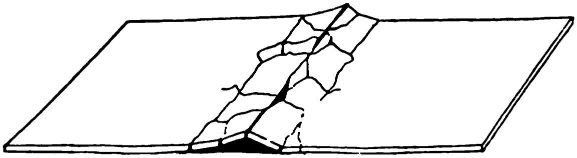


Fig. 38.—A cement walk broken under expansion by sun-heat.

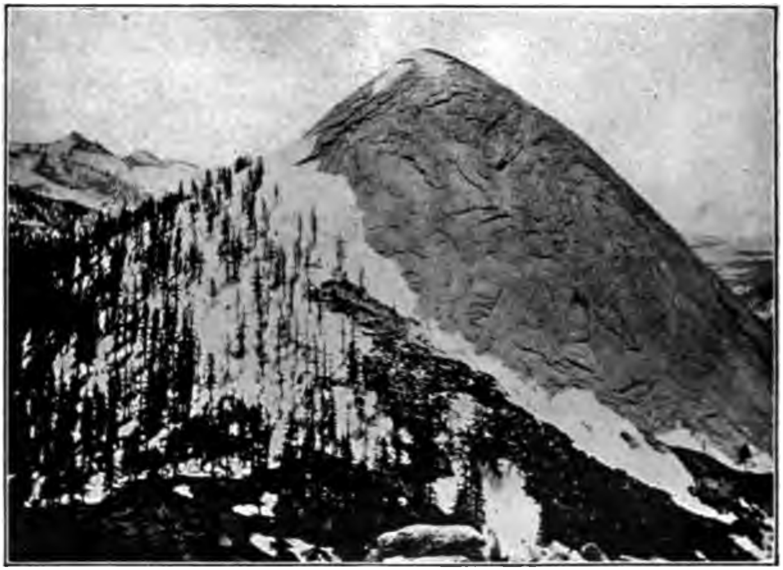


Fig. 39.—Exfoliation on a mountain slope. Mount Starr-King, California.

Chicago. Many bowlders which lie on the surface are seen to be "shelling off" (Fig. 36), and the same thing is sometimes seen on mountain tops (Fig. 39). In high mountain regions where the changes of temperature of the rock are great and sudden, the exposed rock is often much broken. So far has this rock-breaking gone, that the surface of many a sharp mountain peak is covered with cracked and broken rock, so insecure that a touch or a step will loosen many pieces and start them down the mountain (Fig. 40).

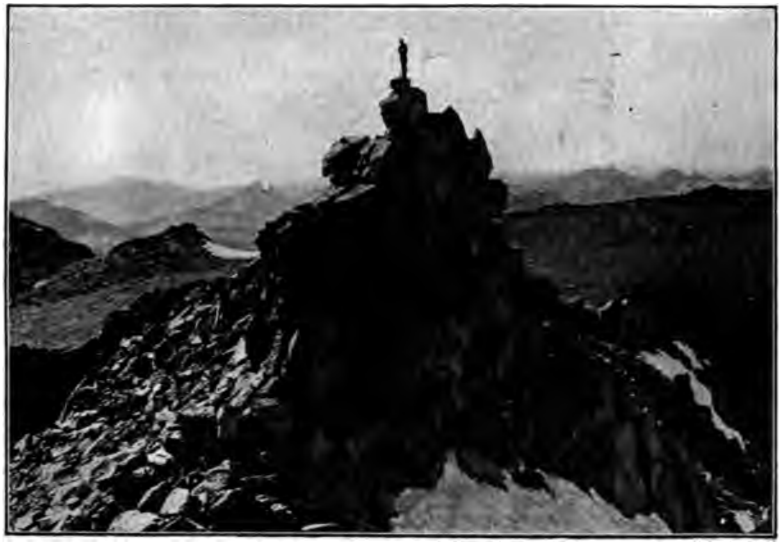


Fig. 40.—Crumbling on a mountain top Kearsarge Pass, Sierra Nevada Mountains Changes of temperature one cause of the broken rock.

Great piles of such debris (called *talus*) bury the bases of many of the western mountains to the depth of many hundreds of feet (Fig. 41). The pieces of talus range from tiny bits up to masses tons in weight.

This process of rock-breaking is a phase of *weathering*. The debris loosened in this way moves from higher to lower levels under the influence of gravity, if it moves at all. The general effect of the process is to make high places lower, and to build up low lands about the bases of steep slopes.

The breaking of rock through changes of temperature is not the work of the atmosphere; but the atmosphere has much influence on the changes of temperature on which the process depends.

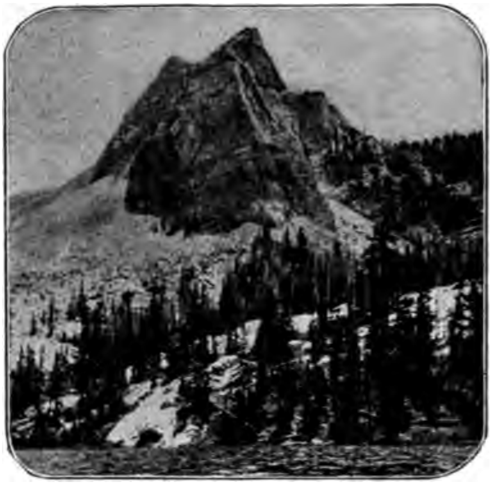


Fig. 41.—Talus at the foot of a peak in the Wasatch Range. (Chamberlin.)

SUMMARY

On the whole, the tendency of the work of the atmosphere and of the work which is controlled by it is to lower (degrade) the surface of the land, and to loosen materials of the surface so that they may be readily moved to lower levels by other agencies. The most important phase of this work is *weathering*, or the preparation of material for removal by other and more powerful agents of erosion. As we shall see, however, the atmosphere is not the only agent concerned in weathering (see p. 68).

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CHAPTER III

GROUND-WATER

GENERAL FACTS ABOUT LAND-WATER

Water is one of the most vigorous agents working on the land. Its activity is seen on every slope whenever it rains hard, and it is seen in every stream, and in the waves of lakes and seas. Even the water in the soil and in the rocks beneath the soil is active, as we shall see.

The great activity of surface-water, like that of air, is due to the ease with which it moves; but since water weighs much more than air, it has more force, and produces greater results.

Source of land-water. The water on the land and in the soil and rocks has fallen from the atmosphere, which always contains some moisture in the form of *water vapor.* This vapor cannot be seen, but it is constantly passing up into the air from all moist surfaces by *evaporation.* Thus any moist surface soon becomes dry in the sunshine or in a warm room, and it becomes dry because its moisture has passed into the air in the form of vapor. Evaporation is going on all the time, both from moist land surfaces, and from the surface of water.

Under certain conditions, some of the water vapor in the air is condensed into drops, and these drops fall as rain; or, if the temperature at which the vapor condenses is below the freezing-point, the moisture freezes as it condenses, forming snowflakes instead of raindrops. The moisture which falls from the atmosphere, whether in the form of rain or snow, is called *precipitation.* The precipitation on the land each year would make a layer of water something like three feet deep, over the surface of the land, if it all fell at one time and were equally distributed. In other words, the average amount of precipitation on the land is probably between 35 and 40 inches a year, if we count a foot of snow as an inch of water. Forty inches of water over the whole of the land would make about 35,000 cubic miles of water. Since the rivers carry only about 6,500 cubic miles of water to the sea each year, it is clear that the larger part of the rainfall is not carried to the sea by rivers.

The fate of rain-water. The water which falls as rain does not remain long where it fell. Some of it sinks beneath the surface, some of it forms pools or lakes, some of it runs off over the surface, and some of it goes back into the air by evaporation.

The amount of the rainfall which disappears in these different ways is not the same for all places. When the rain falls on a steep slope, the water runs off, and little sinks in or evaporates. If it falls rapidly, less sinks in and more runs off over the surface than if it falls slowly. More rain-water sinks into loose soil, such as sand or gravel, than into compact soil, such as clay, and when the soil on which rain falls already contains much water, less can enter than if the soil were dry. Vegetation hinders the flow of water over slopes, and holds it longer on the surface, giving it more time to sink in. Where the air is very dry, more of the rainfall evaporates, leaving less to run off or sink in.

The water which sinks into the ground becomes *ground-water*, and that which flows off over the surface, without sinking, is the *immediate run-off*. Much of the ground-water finally comes to the surface again, as in springs, and some of it joins the immediate run-off in the streams. All the water which the streams carry, whether it has been beneath the surface or not, is the *run-off*.

GROUND-WATER

Its existence. The existence of abundant ground-water is known in many ways. (1) In farming regions, there are wells on almost every farm, and all are supplied with water. Illinois has more than 250,000 farms, and it is probable that the number of wells in the state is double the number of farms. The number of wells in the United States must be several millions, and the amount of water drawn out through them each day is very great; yet the wells rarely go dry. (2) In deep mines huge pumps are often kept at work all the time, in order to keep the mines dry enough for men to work in them. (3) Springs are common in many regions, and their water comes from beneath the surface. These facts show that the amount of ground-water is large.

Its source. Rain-water and snow-water are continually sinking beneath the surface, and as we know of no other source whence it might come, it is thought that the water in the ground is rain-water and melted snow which has sunk beneath the surface.

The connection between rain and ground-water is shown in different ways. Many shallow wells and some springs go dry in times of drought, but when the drought is broken by renewed rainfall, the wells have water again, and the springs flow.

Descent of ground-water. The rain-water sinks into the soil and rock through pores and cracks. In the soil and subsoil, pores are more common than cracks, but in the solid rock beneath the soil, cracks are common, and much water goes down through them. It must descend as far as there are cracks and pores.

The rocks near the surface have more and larger pores and cracks than those at greater depths. Most pores and cracks become very small at a depth of a mile or two, and it is probable that none exist below a depth of five or six miles. If this is true, water does not descend more than five or six miles.

The ground-water surface. If a series of wells be dug in a flat region, where the soil and the rocks below the soil are everywhere the same, the wells would have to be dug to about the same depth in order to secure a constant supply of water. This is illustrated by Fig. 42. If the well at *a* is dug to a given depth, a well at *b* will need to be dug to about the same depth in order to secure an equal supply of water. Other wells at *c* and *d* will also have to be

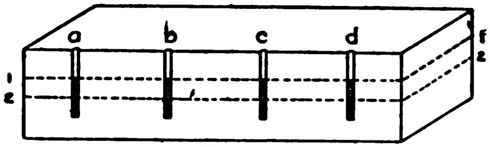


Fig. 42.—Diagram showing a series of wells sunk in a flat tract of land.

about equally deep. Under these circumstances, the water in the several wells will stand at about the same level. This means that the rocks and subsoil of the region, below the level of the water in the several wells, are full of water. The surface below which the subsoil and rock are full of water in any given region is the *water surface* for that region. The water surface is sometimes called the *water table*. In one region, the water table may be 10 feet below the surface of the land, and in another, 100 feet. In dry regions it may be even deeper; but where the precipitation is enough for successful farming, the water surface is seldom more than a few score feet below the surface of the land. The surface soil is rarely full of water except immediately after a heavy rain, or when snow is melting.

Amount of ground-water. The amount of ground-water is not known, for there is no way of measuring it accurately. The best estimates which have been made indicate that the water in the soil, rocks, etc., of the land would probably make a layer something like 1,000 feet deep, if it were spread out over the surface of the land.

The movement of ground-water. The ground-water is constantly moving. This is shown in many ways. (1) If all the water be pumped out of a well, it soon fills again about to its former level, and this shows that water flows in. (2) The constant flow of the thousands of springs shows that ground-water is in movement, for its movement supplies the water of the springs. (3) The flow (*seepage*) of water into mines, quarries, etc., tells the same story.

The reasons why ground-water moves may be readily understood. The rain does not fall equally everywhere. If there is a heavy shower in one part of a flat region, where the ground-water surface is level, the soil and rock where the rain falls become filled with water, and as a result, the ground-water surface is there raised temporarily. Under these conditions, the ground-water will flow from the place where the water surface is higher, to the place where it is lower. In the subsoil or rock, the water spreads more slowly than it would at the surface, because it does not move readily through the small pores and cracks.

The ground-water surface is not always level, even in a region where the rainfall is uniform. Other things being equal, it is higher beneath high land, and lower beneath low land (Fig. 43), and in this case, the water under the higher land moves out to lower lands. The tendency is for the water surface below the high land to sink

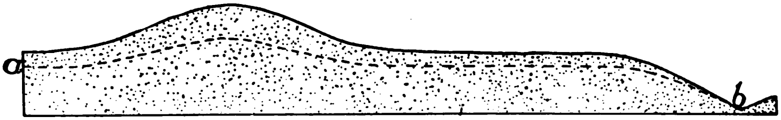


Fig. 43.—Diagram illustrating the position of the ground-water surface (the dotted line) in a region of uneven topography.

until it is as low as that beneath the low land; but in moist climates, it rains so often that the water surface under the hills almost never sinks to the level of the water in the surrounding low lands, before it is raised again by rains. Ground-water is therefore almost always moving out from high lands to low lands.

While ground-water usually flows in the direction of slope, it is sometimes forced upward. Thus, if water moving down through a porous layer of rock, as *b* (Fig. 45), between beds, such as *d* and *f*, which do not allow it to pass through them, finds an opening, it may escape upward, forming a spring, as at *s'*. It may even flow out with great force, as shown by some flowing, or *artesian*, wells (Fig. 50). Some ground-water flows underground to the sea or to lakes, and issues as springs beneath them. Some ground-water, too, seeps out in such small quantities as not to appear to flow. In this case, it does not constitute a spring.

Ground-water moves about to some extent in other ways. Some of it is taken up by roots, and, passing up through the plants, comes out through their leaves into the air. Even in regions where the soil appears to be very dry, evaporation is going on all the time. The pores and cracks of the rock down to the water surface are full of air, and from the water below, vapor passes up into the air in the rock and soil, and thence into the air above.

The rise of vapor from the ground may be proved in a very simple way. If a rubber blanket be spread on the ground on a summer night, or if a pan be inverted on the soil, the under side of the blanket or pan will often be *dripping wet* in the morning, before the heat of the sun affects it. Had the cool blanket or the

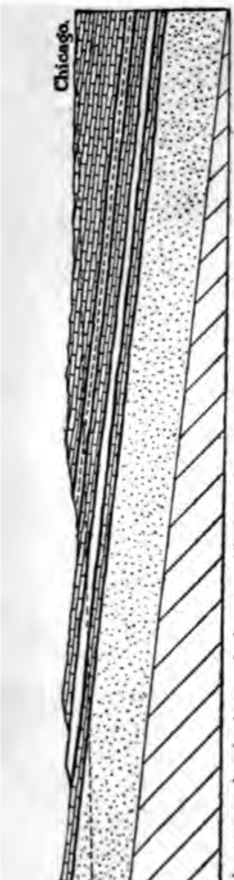


Fig. 44.—A section showing the general relations of the stratified rocks along a line from south-central Wisconsin to Chicago. The thick layer represented by dots is a layer of porous sandstone through which the water descends.

cool metal not been there to stop it, the moisture from below would have escaped into the air above as water vapor. It is escaping unseen all day and all night, and every day and every night, over all land surfaces wherever the air in the soil and below it is more moist than the air above. In this and other ways the ground-water is constantly used up. Rainfall and snowfall, on the other hand, keep renewing its supply.

It is probable that nearly all of the water which sinks beneath the surface sooner or later comes up again in some one of these various ways; but a very small amount of it unites with the solid mineral matter, as in iron rust (p. 39). So long as water remains in the solid combination, it does not again escape to the surface.

The rate at which ground-water moves varies greatly. It depends chiefly on (1) the porosity of the rock or soil, and (2) the pressure of the water. The rate at which water seeps through soils from irrigating ditches in the arid lands of the West, has been determined in many places. In most soils, the rate is from one to eight feet per day; but in very porous soils, it is sometimes as much as 50 feet per day. In a widespread formation of sandstone which underlies southern Wisconsin and northern Illinois, the rate of movement of ground-water has been estimated at half a mile a year. At this rate rain-water which enters this formation 100 miles from Chicago (Fig. 44) would reach that city in about 200 years. The water which sinks to great depths and into the very small pores and cracks, moves with extraordinary slowness, and some of it remains entrapped within the rock for very long periods of time.

Springs

All water issuing from beneath the surface is ***seepage.*** Water issuing through a natural opening in such quantity as to make a distinct current is a *spring*. Springs may occur wherever there are natural passageways through which the ground-water may reach the surface. Such passageways arise in various ways. Two cases are illustrated by Fig. 45. In one case the water descends through a more or less porous bed of rock, *c*, to a layer, *a*, which is compact. The water flows along this layer until the layer comes to the surface (or *outcrops*) and there the water flows out as a spring, *s*. In the other case, the water moves underground through the porous layer *b*, under pressure, until it reaches a crack which leads up to the surface. If the crack is open enough to afford a free passageway, the water may follow it up to the surface, as at *s′*. A spring will flow in such a situation only when the opening is lower than the water surface in the layer of rock which carries the water. This sort of a spring is similar to a flowing well in principle, but in the latter case the opening is made by man.

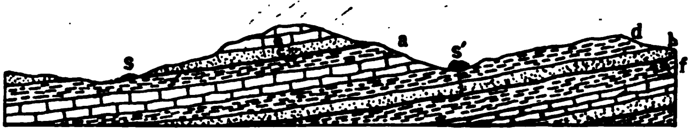


Fig. 45.—Diagram to illustrate two types of springs, as explained in text. The type represented by *s* is more common than the other.

Temperature. The temperature of spring-water is very variable. Most springs seem cold in warm weather, and there is a popular impression that springs are cooler in summer than in winter; but this is not the case. The impression arises from the fact that the water is much cooler than the air in summer, and so *seems* cold, while in winter, the water is warmer than the air, and so *seems* less cold than in summer. Springs whose waters come from great depths vary little in temperature during the year, while those whose sources are but little below the surface are colder in the winter than in summer. The reason is, that the warmth of summer and the cold of winter are most extreme at the surface, and become less so with increasing depth. Below the depth of 50 or 60 feet, in middle latitudes, the temperature does not change much with the seasons, and springs which draw their water from depths greater than 50 or 60 feet vary little in temperature, while those which draw their supply from lesser depths vary more.

Some springs are warm, and a few are hot. Where spring-water is hot, it is commonly because it has been in contact with hot rock. In many cases, the hot rock is probably lava which has come up from greater depths so recently that it has not yet become cold. It may be lava which was forced upward toward the surface but not to it, or it may be the deeper parts of lava which flowed out on the surface. There are more than 3,000 hot springs in the Yellowstone National Park.

Mineral and Medicinal Springs. All spring-water has some mineral matter in solution; but a spring is not commonly called a *mineral spring* unless it contains (1) much mineral matter, (2) mineral matter which is unusual in spring-water, or (3) mineral matter which is conspicuous either because of its color, odor, or taste.

Many mineral springs are thought — and sometimes rightly — to have healing properties, and so are known as *medicinal springs*. Many of the famous watering-places and resorts for invalids are at hot mineral springs. The Hot Springs of Arkansas, of South Dakota, and of Carlsbad (Bohemia) are examples. Many springs which are charged with gases are called mineral and medicinal, even though their waters are worthless for healing purposes. Hot water dissolves most kinds of mineral matter more easily than cold water does, and so hot springs generally contain much mineral matter.

Geysers. In some parts of the world, the water of hot springs is forced out violently from time to time. Such springs are called *geysers*. There are more than 100 geysers in the Yellowstone National Park, and there are geysers in Iceland and in New Zealand, though some of the geysers of the latter island were destroyed by *volcanic eruptions, in 1886.* Geysers occur only in regions of recent volcanic activity. Some geysers send up boiling water and steam to a height of 200 feet or more, though this is quite above the average.

Some geysers erupt frequently, and others infrequently. The eruptions of some occur at regular times, and those of others take place irregularly One of the geysers in the Yellowstone Park is named "Old Faithful," because it discharges its waters at nearly regular periods of about an hour. The eruptions from this geyser are, however, a little less frequent and a little less regular than formerly. In general, geysers which have been known for long periods of time discharge their waters less and less frequently; as time goes on.

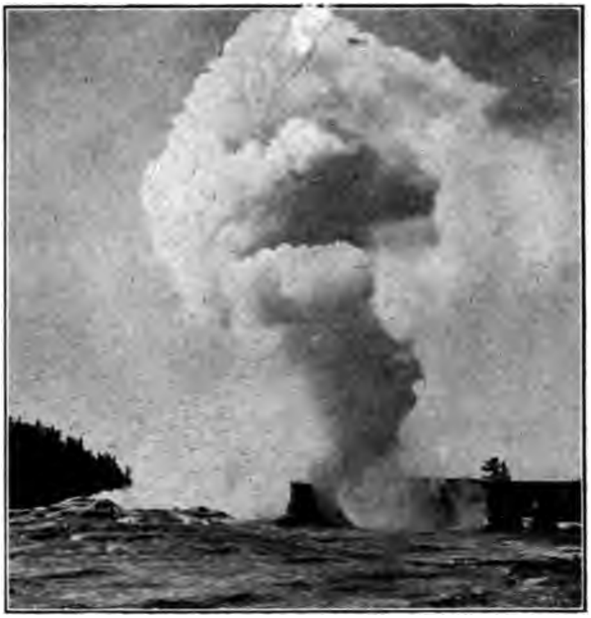


Fig. 46.—Giant Geyser, Yellowstone National Park. (Wineman.)

The features which may be seen generally at a geyser are the following:

(1) An opening leading down to unknown depths. Though

this is sometimes called the *geyser tube*, it is probably not always in the form of a tube. (2) A shallow basin about the opening, often filled with water. This is sometimes, though not always, in the top of a mound. In some cases there is an irregular mound perforated by openings, instead of a basin about the top of a tube (Fig. 48). Both basins and mounds are composed of mineral matter (commonly silica) which has been deposited by the water which has issued from the geyser. (3) At the time of discharge, much steam as well as liquid water issues.

It seems certain that steam is the force which ejects the water from a geyser. It is believed (1) that ground-water enters the geyser tube much as it enters a well; (2) that the walls of some part of the tube are of hot rock; (3) that the water in the tube is brought to the boiling temperature at some point in the tube below the top of the water; and (4) that when this takes place, the water which is converted into vapor expands about 1,700 times and forces out all the water above.

Fig. 47. –General view of the upper Fire-Hole Geyser basin, Yellowstone Park. (Detroit Photo. Company.)

The reason why the water in a geyser tube is shot out, and at intervals, while the water in an open kettle is not, is found in the difference in the shape of the vessels holding the water. When water is heated, it expands. When water is heated in a kettle, *that at the bottom* rises readily (the motion is called *convection*) to the top, so that there is a nearly uniform temperature throughout. Any water vapor that may be formed at the bottom rises readily through the water and escapes into the air. The geyser tube is much deeper than the kettle, and in places its diameter is probably small. The tube is also more or less crooked. Both its smallness and its crookedness interfere with the rise of the water (by convection) heated below, and the result is that water below the surface is brought to the boiling temperature, under conditions which do not allow the vapor to escape freely into the air. Hence steam is formed in quantity below the surface, and by its great expansion blows out the water above.

How

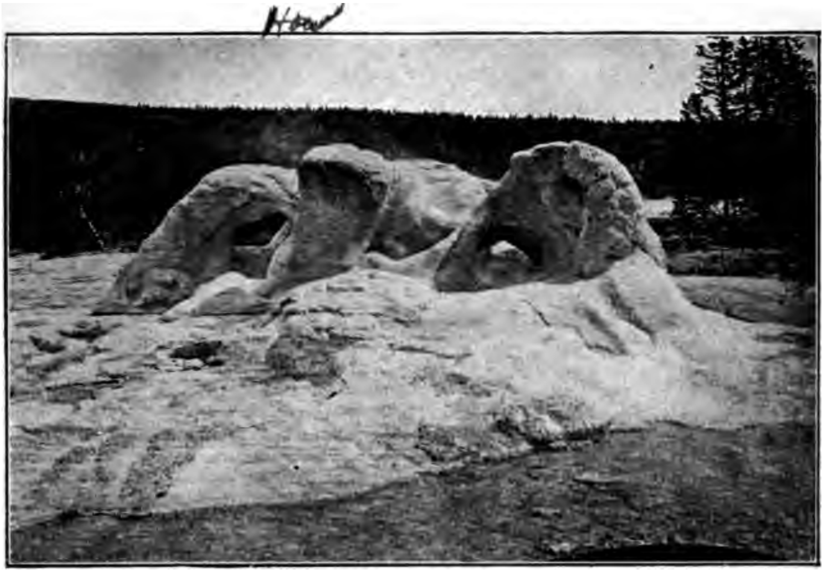


Fig. 48.—Cone (or crater) of Grotto Geyser, Yellowstone Park. (Detroit Photo. Company.)

If a stone or a clod of earth, or almost any other solid object be thrown into a geyser, its eruption may often be hastened a little, because such things interfere with the convection of the water in the tube. They help to hold the hot water down where it is being heated, and so help it to reach a boiling temperature at some point below the surface a little sooner than it would do otherwise. Soap, especially, is supposed to hasten a geyser's eruption. Its effect is probably somewhat less than is usually believed. Anything which thickens the water hastens the eruption, because convection is less free in a thick fluid than in a thin one.

Geyser-water is constantly cooling the hot rock beneath the surface, and in time the rock will cease to be hot enough to boil the water. Geysers will then cease to exist, unless new supplies of hot lava are forced up from below. In the Yellowstone Park, some geysers have died out since the region became known, but little more than thirty years ago. New geysers, on the other hand, have come into existence in the same region during this period.

ARTESIAN AND FLOWING WELLS

When the water in a well rises to or above the surface, the well is said *to flow*. Flowing wells are not unlike springs whose waters spout up as they issue. The chief difference between them is that the opening in one case is natural, while in the other it was made by man. Formerly, artesian wells were regarded as the same as flowing wells. Nowadays, the name "artesian" is often applied to deep wells, whether they flow or not. The name "artesian" came from Artois, France, where there was a famous well of this sort.

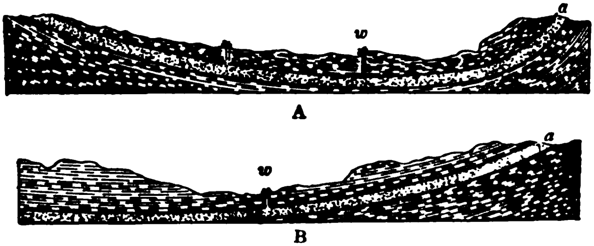


Fig. 49.—Diagram illustrating the conditions favorable for artesian wells. In A, the porous bed *a* is in the form of a basin; in B, it merely dips.

Fig. 49 illustrates the general conditions necessary for flowing wells. They are the following: (1) A porous layer or bed of rock, *a*, underlying one which is not porous, and which prevents the water from escaping upward until it is penetrated by the well hole, *w*. The porous bed should come to the surface in a region which is somewhat higher than the site of the well. (2) Enough rainfall, where the porous bed comes to the surface, to keep the porous bed well filled with water. Under these conditions, the water beneath *w*, in the stratum *a*, is under the pressure of the water in the same stratum at higher levels, and if a hole is made down to it, it will gush up (Fig. 50).

Artesian wells may be but a few feet deep, or they may be thousands of feet deep. There is an artesian well in Berlin more than 4,000 feet deep, one in St. Louis nearly 4,000 feet, and one in Cincinnati nearly 2,500 feet deep, while the deepest one in Chicago is some 2,700 feet deep. There are numerous artesian wells in New Jersey less than 100 feet in depth.

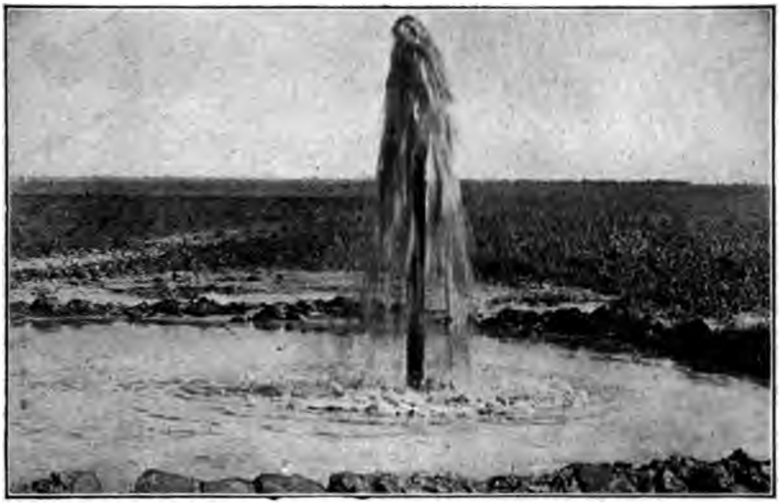


Fig. 50.—An artesian well ten miles northeast of Mitchell, South Dakota. A pipe has been inserted into the well-hole and the water flows up through the pipe. (U. S. Geol. Surv.)

Many villages and small cities get their water from artesian wells. Charleston, S. C., Galveston and Fort Worth, Texas, Camden, N. J., and Rockford, Ill., are among the cities supplied partly or wholly in this way. No great city, however, such as New York, Chicago, Philadelphia, etc., gets its public supply of water from such wells, and probably could not get enough in this way.

In the semi-arid region of the Great Plains, and at various other places in the West, as, for example, in some parts of California, water from deep wells is extensively used for irrigating the land.

THE WORK OF GROUND-WATER

Ground-water does two kinds of work: (1) It dissolves mineral matter, and it changes the character of the rock through which it flows in more ways than one. Changes of this sort are *chemical changes.* (2) Where it flows in streams, as it sometimes does, it wears the channels where it flows, much as streams on the surface do. If it flows over clay or sand, it may pick up particles of mud and rock. Most ground-water is in the pores of rock, not in channels, and its *mechanical* work is much less important than its chemical work.

Chemical Work

Solution. As already stated, rock is dissolved, to some slight extent, by the ground-water which passes through it. This is shown by the fact that all water which comes out of the ground has some mineral matter in solution. When such water is evaporated, and often when it is boiled, it leaves a trifling residue, which in time becomes very noticeable on the inside of boilers and kettles. On the inside of a tea-kettle there is frequently a thin coating composed of mineral matter which was in solution in the water, and which was left behind when the water was heated or evaporated.

Pure water does not dissolve mineral matter readily; but ground-water is not pure, for in falling through the atmosphere it dissolves some of its gases, and in sinking through the soil it takes up the products of plant decay, so that when it becomes ground-water it contains various impurities. With these impurities in solution, ground-water dissolves most sorts of mineral matter more readily than pure water would.

The first work of ground-water, then, is solution, or the subtraction of material from the rocks. The amount of mineral matter brought to the surface through springs is very great. The springs of Leuk (Switzerland) have been estimated to bring to the surface more than 2,000 tons of gypsum in solution yearly. In the same time the springs of Bath (England) bring up enough mineral matter in solution to make a column 9 feet in diameter and 140 feet high.

Caverns. One result of the solvent work of ground-water is that rock is made porous. Small pores and cavities are more numerous than large ones, but some of the openings produced in this way are very large. Many underground caves, such as Wyandotte Cave in southern Indiana, and Mammoth Cave in Kentucky, were dissolved out by ground-water. Such caves are found chiefly in limestone, for this is the most soluble of the common rocks. An underground cave is not, as a rule, one great chamber, but is made up of many chambers or rooms connected by smaller passageways (Fig. 51). The total length of the passageways in Wyandotte Cave is more than 23 miles, and it has been estimated that there are 200 miles of passageways large enough for a man to get through in an area of 10 square miles about Mammoth Cave. Some 500 caves are known in one county in Kentucky, and it has been thought that the length of all such passageways in this state may be some thousands of miles. These passageways are enlarged at many points so as to form great rooms.

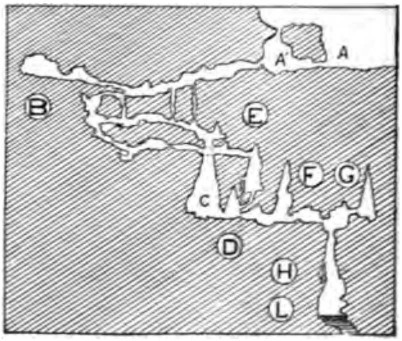


Fig. 51.—Vertical section of a cave in France. B, a chamber without outlet; C, D, E, F, G, H, cone-shaped chambers. (Robin.)

Water is constantly seeping into caves from all sides and from the tops. This water has mineral matter in solution, some of which is deposited in the caves, either in icicle-like columns, called *stalactites*, hanging down from the roof, or on the floor of the cave, as *stalagmites* (Fig. 52), and some of it, too, forms crystals and sheets on the walls (Fig. 53). The stalactites, stalagmites, and crystal-covered walls are among the most interesting features of caverns. Small streams sometimes flow through caves, but in no case now known is there a stream of such size that it would seem like a large river, if it were on the surface.

Cavern life. Caverns do not seem to furnish conditions favorable for most sorts of life, for most plants and animals need light. Yet there are a good many varieties of animals in the water and in the damp air of caves. These animals are so like some of those living above ground in the same region, that they are believed to be the descendants of animals which got into the caves from the surface.

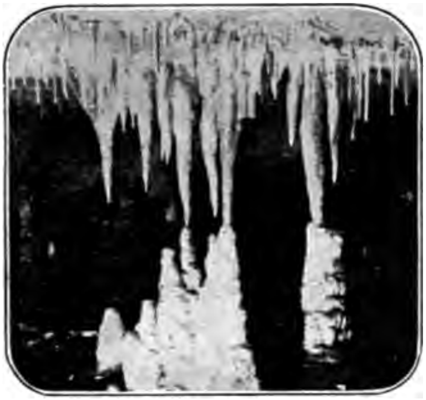


Fig 52.—A view in Marengo Cave, southern Indiana. (Hains.)

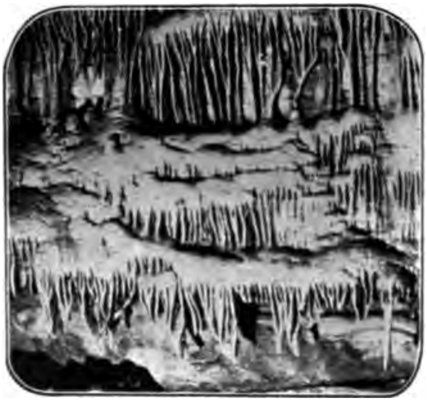


Fig. 53.—A view in Marengo Cave. (Hains.)

If we compare the animals in the caves with their relatives above ground, we find that the former show some peculiar features. In the first place, they are less brightly colored. This is probably because of the absence of sunlight, which seems to have much to do with producing color in animal life. In the second place, the eyes of the cave-animals are poor, or sometimes wanting altogether. Some of the fish have no eyes. Among the crayfish, some have good eyes, some have eyes too imperfect to be useful for sight, and some have none. Among the beetles, there are species in which the males have eyes, while the females have none. From these and other facts we may infer that the eyes of animals in the dark caves tend to disappear.

A third peculiar feature of cavern animals is that their organs of touch, such as antennæ, are very well developed. In the darkness the sense of touch is much more useful than the sense of sight.

In Europe caverns were sometimes the homes of primitive man. The evidence of this is that the bones of men, as well as tools of various sorts made by them, are found in the caves. Here, too, are found the bones of large animals which were killed for food or fur and taken to the caves. On the bones of such animals and on pieces of slate or wood, there are sometimes drawings, and some of these drawings are of animals which no longer live in the region where the caves are. From this we infer that the people who lived in the caves lived there a long time ago. Carnivorous (flesh-eating) animals also lived in some caverns long ago. The caves seem to have been their lairs, and to them they took their prey.

Limestone sinks. The roofs of some underground caves fall in, making sink-holes (*limestone sinks*, Fig. 54). Such sinks are so numerous in some places (parts of Kentucky and Tennessee) that the surface about them is not cultivated. Similar depressions arise from the dissolving of limestone at the surface.

From limestone sinks tunnels often lead down to the caves. Some of these openings have been stopped up by man, because cattle, going down into the sinks for the grass about the moist borders of the pit, occasionally fall in.

Dissolved mineral matter carried to the sea. Much of the ground-water finds its way to rivers, after it seeps out, and the larger part of the mineral matter in solution in rivers has come from the ground-water which has flowed to them. All the rivers of the earth are estimated to carry nearly five billion tons of mineral matter to the sea in solution each year.

The transfer of so much mineral matter in solution from the land to the sea must lower the land. On the average, the land surface is lowered in this way about one foot in 13,000 years.

Some of the mineral matter carried to the sea in this way remains in the sea-water. Salt, for example, is one of the substances carried by rivers to the sea; and it is probable that the larger part of all the salt ever carried to the sea remains there to this day. On the other hand, much of the mineral matter of the sea is used by the animals (and some plants) of the sea for making their shells, tests, bones, etc., and these are left on the sea bottom when the animals die.

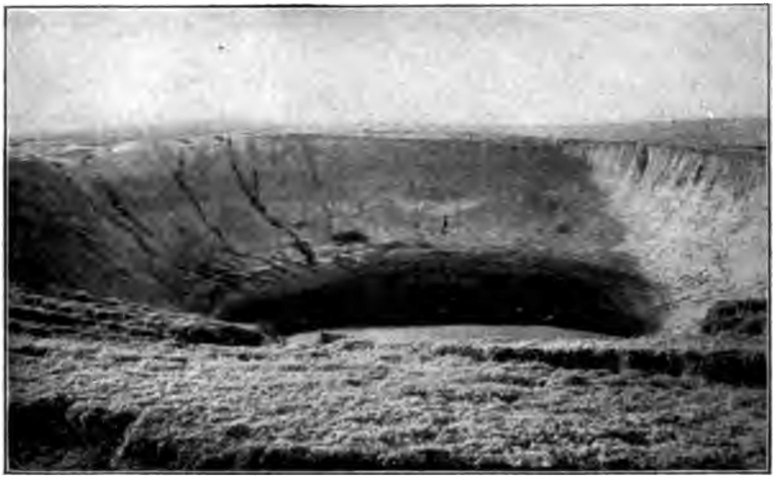


Fig. 54.—A sink-hole of recent development near Meade, Kan. (Johnson, U. S. Geol. Surv.)

Deposition. After dissolving mineral matter from the rocks, ground-water sometimes leaves a part of it in the pores and cracks of the rock through which it flows. In this way it tends to fill up cracks. When cracks in the rock are filled or partly filled by mineral matter deposited from solution, they become *veins*

(Fig. 55), and some rocks are full of them. Ores of gold, silver, lead, zinc, etc., often occur in veins. These metals, or the compounds which contain these metals, do not always completely *fill* the cracks, but are mingled with a larger amount of mineral matter which is not valuable.

In general, ground-water dissolves more near the surface, and deposits more at greater depths. The mineral matter deposited from solution sometimes cements the loose parts of rock together, making the whole more firm. Sand may be cemented into sandstone in this way, and gravel into conglomerate.

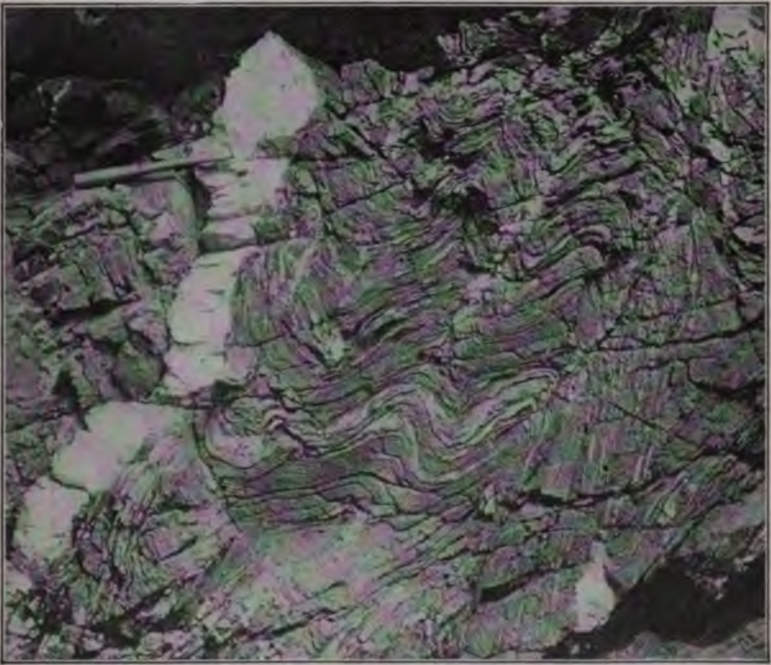


Fig. 55.—A quartz vein in contorted schist. Muchals Caves, Kincardineshire, Scotland. (H. M. Geol. Surv.)

The mineral matter dissolved in ground-water is often brought to the surface and deposited there. The deposition is brought about in various ways, among which are the following: (1) When water evaporates, the mineral matter dissolved in it is left behind. This is one of the reasons why kettles in which water is boiled become coated with mineral matter. (2) Certain gases dissolved in water help it to dissolve mineral matter. If water contains much gas, and if the gas escapes, as it is likely to when it is heated or when it comes to the surface, some of the mineral matter in solution may be deposited. (3) Warm spring-water often gives up what it held in solution, when it cools. (4) Microscopic plants sometimes grow in the waters which issue from hot springs, as in the Yellowstone Park. These tiny plants, by some process not well understood, extract mineral matter from the water, and cause it to be deposited (Figs. 46, 48, and 56).

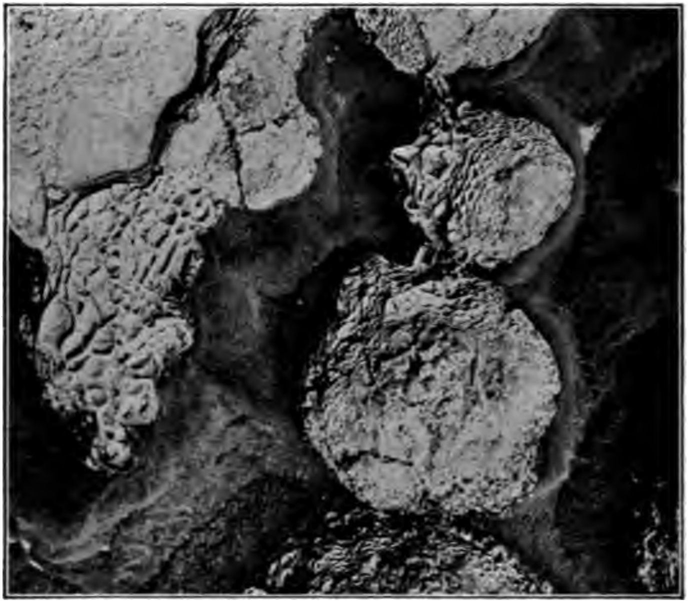


Fig. 56.—Deposits of silica from geyser waters in the basin of the Great Fountain Geyser, Yellowstone Park.

Solution and deposition may be going on at the same time, *and often in the same place.* That is, the water may be dissolving one substance while it is depositing another. Thus the substance of a buried shell, or of coral, may be changed, while its form is preserved. In this case the original material is dissolved and carried away, at the same time that other material is left in the place of that dissolved. In the same way, the substance of wood may be replaced by mineral matter, giving rise to *petrified wood,* or wood "turned to stone" (Fig. 57). Such changes probably take place slowly, the mineral matter which was in solution in the water replacing the woody matter as it decays.

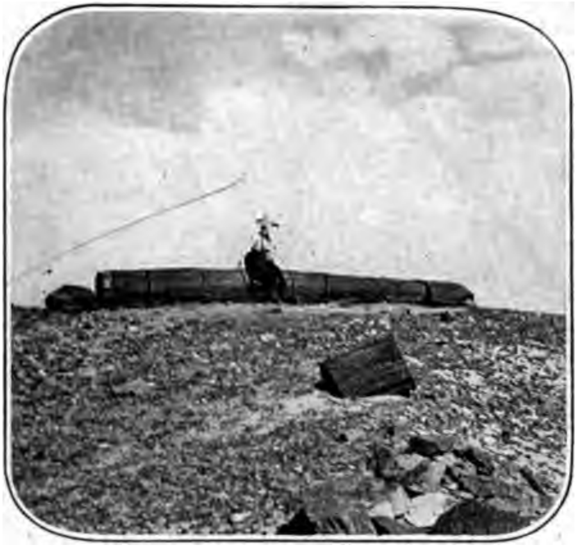


Fig. 57.—A petrified log near Holbrook, Arizona (Atwood.)

Summary. From the preceding paragraphs, it will be seen that ground-water brings about various changes in the rocks. These changes take place slowly, but they are going on all the time. In the long course of time, they are so great that an eminent geologist has said, "Given time enough, and nothing in the world is more changeable than the rocks."

Many of the chemical changes brought about by the ground-water, like those brought about by the atmosphere, tend to make the rock crumble.

Mechanical Work

Abrasion. The mechanical work of ground-water is slight. Ground-water is rarely gathered into large streams; but where even small streams exist, they tend to enlarge their channels by erosion, somewhat as surface streams do.

Slumping, sliding, etc. Indirectly, ground-water helps to bring about changes of another sort. When the soil on a steep slope becomes full of water, its weight is greatly increased, and at the same time the water makes it move more easily. Under these circumstances, it sometimes slides down. Such movements are known as *slumping* or *sliding*. If the movement is on a large scale, it is sometimes called a *landslide*. Slumping is very common on the slopes of hills composed of clay or other earthy matter (Fig. 58).

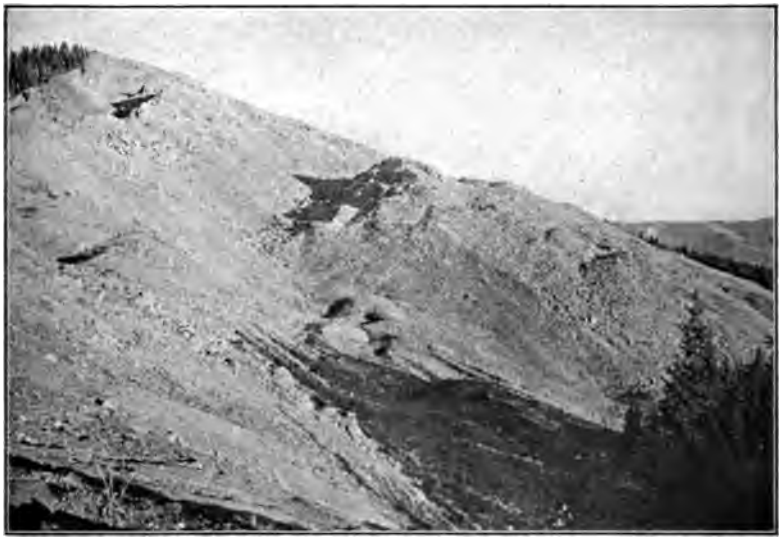


Fig. 58.—South face of Landslip Mountain, Colo. The protruding mass in the center has slumped down. (U. S. Geol. Surv.)

Many destructive landslides have been recorded, but a few facts about a recent one will illustrate the phenomena of all. On the 29th of April, 1903, there was a slide on Turtle Mountain, Province of Alberta, Dominion of Canada. Here a huge mass of material, nearly half a mile square, and probably 400 to 500 feet deep, suddenly broke loose from the steep face of the mountain, and slid down into the valley below. It crossed the valley, which was half a mile wide, and even rose a few hundred feet on the other side. When it came to rest, the material which had slidden down was spread over an area of a little more than one square mile. The length of the slide was about two and a half miles, and it is estimated that the time which it took was not more than 100 seconds The heavy rainfall of the preceding year had filled the rock with water, and the earthquake tremors which occurred shortly before the slide are believed to have also hastened the catastrophe. Extensive tunnels at the base of the mountain, made for mining, may also have played a part by making the understructure less stable. Many lives were lost, and many buildings destroyed.

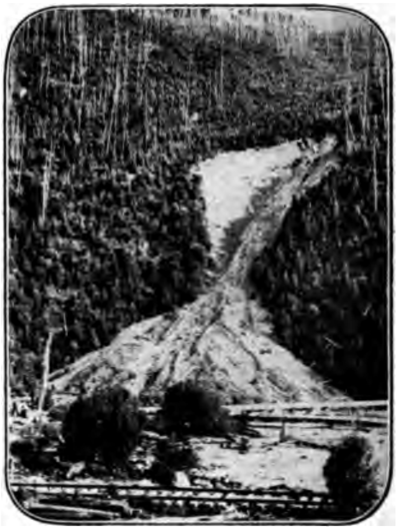


Fig. 59.— Another type of landslide, near Wardner, Idaho. (Fairbanks.)

Instead of sliding down rapidly, the surface earth sometimes moves down with extreme slowness. This sort of movement is *creep*. It is often too slow to be seen, but it results in the accumulation of mantle rock, especially earthy matter, at the bases of slopes. Railways at the bases of steep slopes of clayey material are sometimes pushed out by the creep of the clay, and in some places the tracks have to be taken up and laid down anew frequently, especially in wet seasons.

Weathering

Some of the processes of weathering have already been mentioned, but it may be added that the chemical changes produced in the rock by the atmosphere, the mechanical changes brought about by variations of temperature, and the chemical and mechanical changes caused by ground-water, all conspire to alter the surface of exposed rock, so as to cause it to crumble and waste away

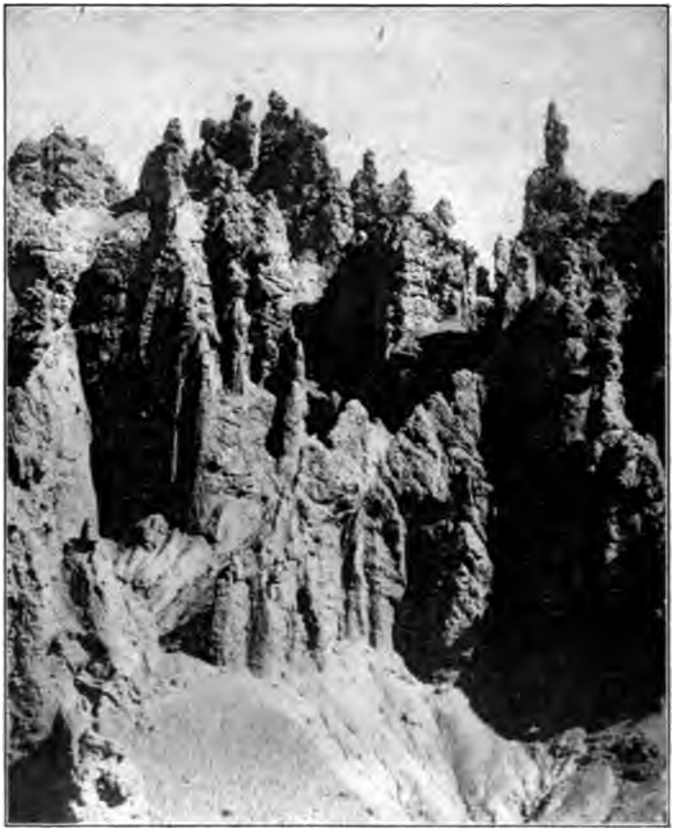


Fig. 60. Weathered lava, Yellowstone Park. (U. S. Geol. Surv.)

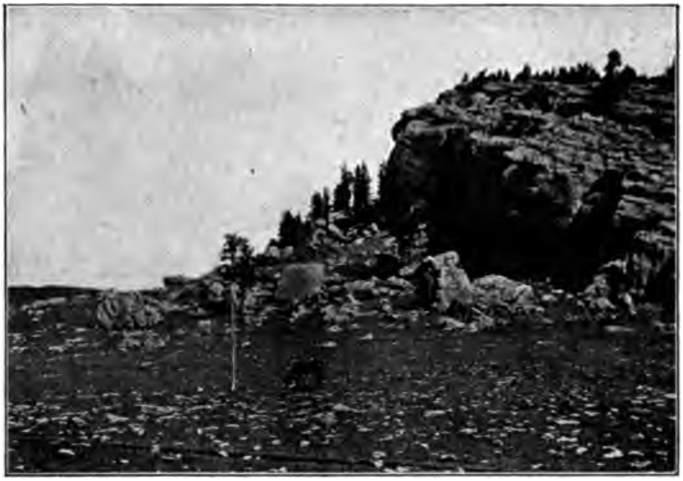


Fig. 61 —A cliff of limestone with talus blocks which have weathered off. Crazy Woman Hill, Wyoming. (Hole.)

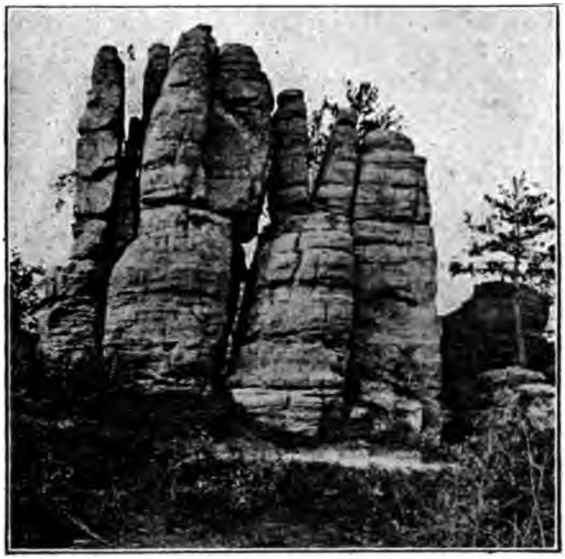
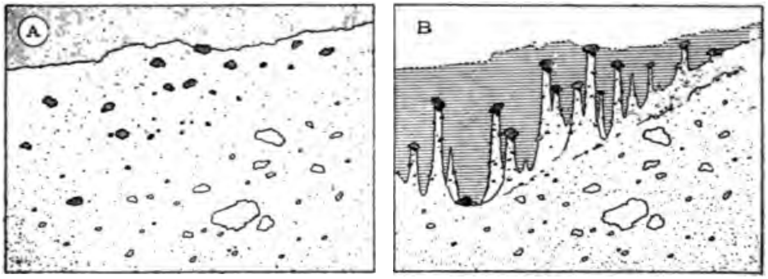


Fig. 62.—A group of sandstone columns weathering away. The surrounding rock has been removed by erosion, and the rock which is here is being weathered away along the cracks and over the whole surface. Elevations of this sort will soon disappear. Central Wisconsin. (Bennett.)

We have already seen (p. 41) that the surfaces of the bowlders of the field are often scaling off or crumbling. They are often discolored, even when they seem firm, and from the walls of stone buildings, from monuments, and from other stone structures, flakes of stone sometimes scale off. The upper layers of stone in a quarry are often broken, and different in color from those lower down. Inscriptions on tombstones are often indistinct, and they have sometimes disappeared completely from stones which are but a few score years old. In all these cases some change has taken place in the rock, whereby its outer part is wasted away. The result is the *weathering* of the rock.



Figs. 63 and 64.—Diagrams showing the formation of earth pyramids capped by pieces of rock. *A* represents the original condition. *B* represents the same after erosion has removed some of the earthy material. (Robin.)

It is to be noticed that weathering is not one process, but many processes, of which those mentioned are but a part. Plants and animals also assist in rock-breaking and rock-decay. The roots of the former penetrate the soil, loosening it, and thereby make it easier for water to get below the surface. Roots sometimes grow in cracks in the rock, and as they grow they act like wedges (Fig. 66). Large masses of rock are sometimes loosened in this way. When a tree is uprooted, the ground is torn up (Fig. 67), and rock material to the depth of several feet is at times exposed to the action of freezing water, air, and rain. Burrowing animals of all sorts loosen the ground, and develop channels for the entrance of water. Even small animals, like ants and earthworms, do an important work in this connection. In Massachusetts, ants have been

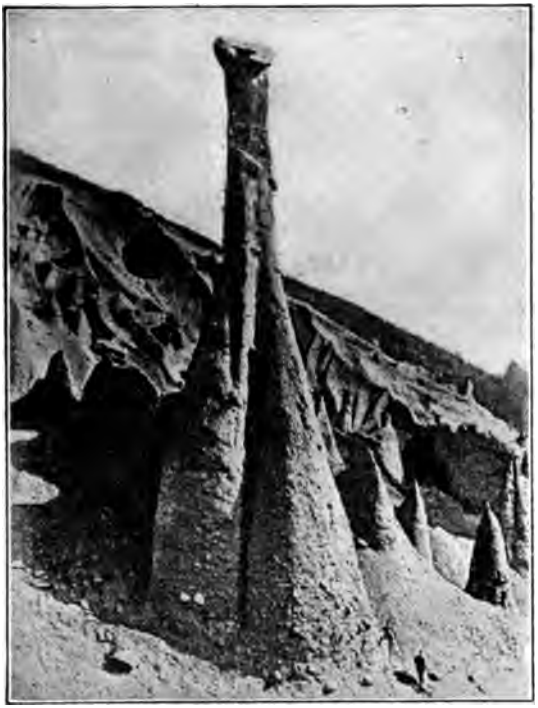


Fig. 65.—A single column of the type shown in Fig. 64. (Kilian.)

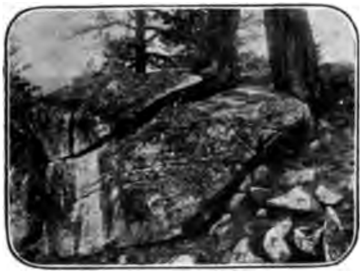


Fig. 66.—A tree growing in a crack in the rock. The growth of the tree pries the parts of the rock apart, thus widening the crack. Sierra Nevada Mountains, California. (Fairbanks.)

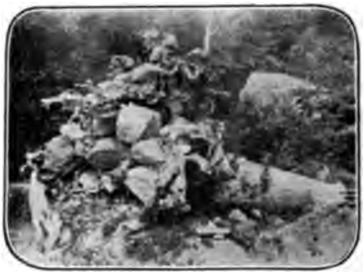


Fig. 67.—Masses of rock in the roots of an upturned tree. Yosemite Valley, California. (Fairbanks.)

estimated to bring one fourth of an inch of fine soil to the surface each year, while Darwin estimated that the earthworm brings 7 to 18 tons of material per acre to the surface each year.

The importance of rock-weathering is great. Much soil is but weathered rock, and without the weathering of rock, much of the land would be free of soil, and without vegetation. The weathering of the rock also prepares fine material for removal by wind or water.

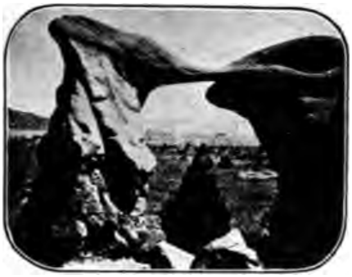


Fig. 68.—Curious forms of weathered rock. Goblin's Archway, Last Chance Creek, Utah. (Hillers.)

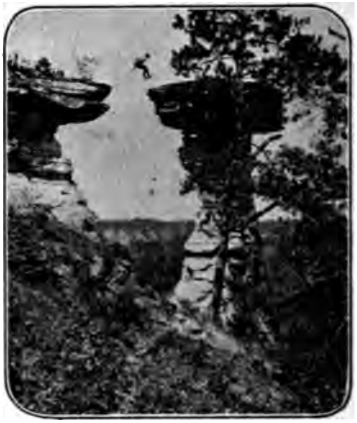


Fig. 69.—Stand Rock; a pillar of rock which has been separated away from the upland to the left by the widening of a crack. Dells of the Wisconsin. (Bennett.)

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CHAPTER IV

THE WORK OF RUNNING WATER

Streams are of common occurrence in most lands. Only in desert regions, such as the Sahara, or in areas covered with snow and ice, like Greenland, are there extensive tracts without them. Though a few streams, like the Mississippi and the Amazon, are very large, small ones are far more numerous.

Some streams are sluggish, and some are swift. Even those which flow slowly under ordinary conditions may become very swift in times of flood, and at such times their force is often terrible (Fig. 70). Occasionally they sweep away bridges, dams, and even the buildings which stand upon their banks. The strong beams and rods of the bridges, and the steel rails of railways, are sometimes bent as if they were twigs by the force of the flood which follows

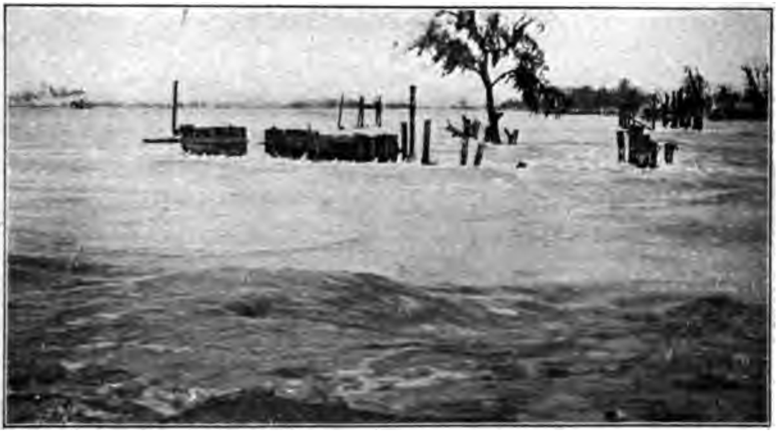


Fig. 70.—A raging river. Flood of the Mississippi River breaking through its levees. Louisiana. (U. S. Weather Bureau.)

an exceptional rain, or the rapid melting of a large body of snow (Fig. 71). The destruction or the weakening of bridges by flooded streams is a common cause of railway accidents. The force of a stream is no less where there are no bridges or buildings, and its banks and bed are readily and effectively worn by the swift current.

The force of running water is often evident even when streams are not in flood. Many small mountain brooks are so swift that it is difficult to stand or wade in them, although they are no more than a foot or two deep. Again, the force of running water is seen in the rapids and falls of streams, and is most impressive in the case of such a fall as Niagara. The force of the waterfall here is estimated at four million horse-power. Even sluggish streams may have great force. The currents of many such streams are made to work the machinery of thousands of mills throughout the land, and the force of the machinery in the mills is often impressive, even when the moving water which turns it makes little show of strength.

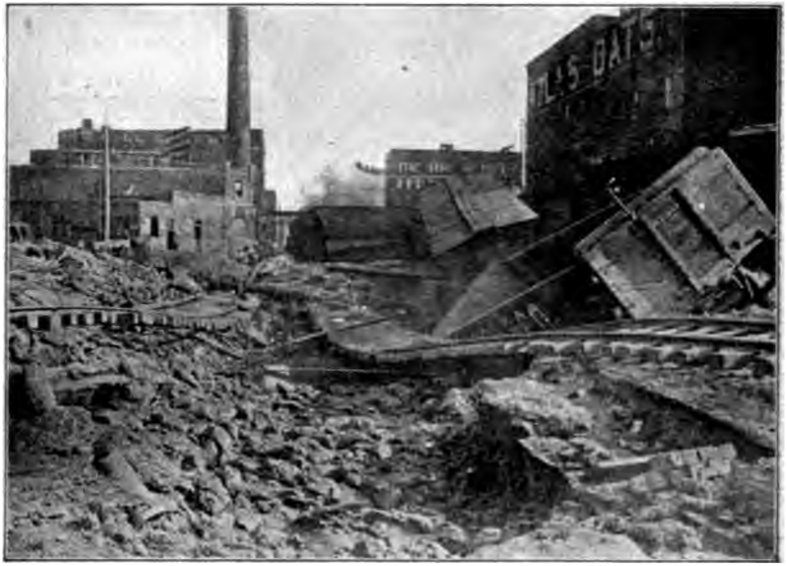


Fig. 71.—Scene in the freight yards of Kansas City after the flood of 1903. (U. S. Weather Bureau.)

All streams, taken together, send about 6,500 cubic miles of water to the sea each year. Since the mean height of the land above the sea is nearly half a mile, these 6,500 cubic miles of water fall, on the average, nearly half a mile before they reach the sea. If this amount of water fell straight down from a height of half a mile, its force would be very great. Though the water in streams descends gradually from higher to lower levels, it has the same amount of energy that it would have if it fell the same distance straight down. A part of this energy is spent in wearing away the sides and bottoms of the valleys, and the large amount of mud, sand, and gravel moved by streams shows that the wear is great.

Sources of stream water. Most streams derive the larger part of their water from the immediate run-off, and from ground-water; but many of them receive contributions from ponds and lakes as well, and a few, like the St. Lawrence, receive most of their water in this way. Others get water from the snow and the ice of mountains. The Mississippi, as well as most other great rivers, receives water in all these ways. The immediate run-off, the ground-water, the water of the lakes, and the ice of the mountains, all have their sources in the rain and snow; so that rivers, like springs and wells, depend on moisture from the atmosphere for their supply of water.

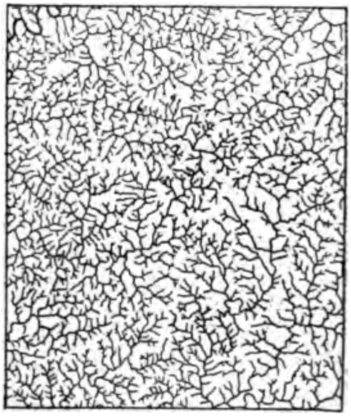


Fig. 72.—Map showing the many streams of a humid region. Central Kentucky. The area is about 225 square miles.

A direct connection between rainfall and rivers may be inferred from various familiar facts: (1) Streams are more numerous in regions where the rainfall is plentiful (Fig. 72) than in those where it is scarce (Fig. 73). (2) Multitudes of small streams spring into being with each heavy fall of rain, and with each period of rapidly melting snow, to disappear again soon after the rain ceases, or after the snow is gone. (3) Streams are swollen after rains, and swollen most after heavy rains. (4) Many small streams which flow during wet weather disappear in times of drought.

If a slope of land were perfectly even, like the slope of a smooth roof, the immediate run-off would flow in a sheet. There are slopes so even that their immediate run-off moves in this way; but on most slopes, even those which appear to be regular, there are some unevennesses, so that, although the run-off which follows a rain may start as a sheet, it is soon gathered into rills or streamlets which follow the depressions of the surface. The smallest streamlets unite to form larger ones, and the little rills, after many unions with one another, reach valleys where there are *permanent streams*. These may be small, when they are called *creeks* or *brooks*; or large, when they are called *rivers*. Streams which flow but part of the time, as after a rain-storm, during wet weather, or only a part of the year, are *temporary* or *intermittent streams*.

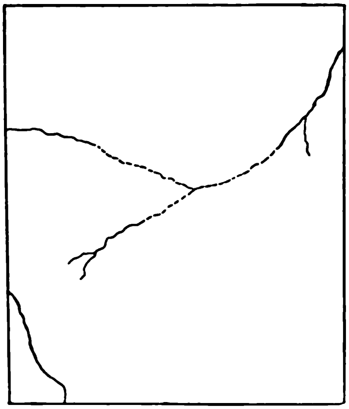
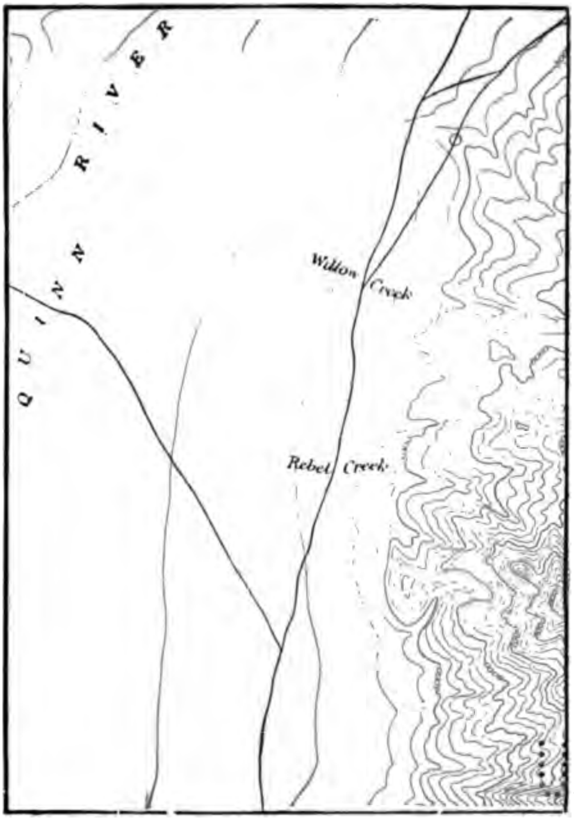


Fig. 73.—Map showing the few streams of an arid region. Northern Arizona. The area is as great as that shown in Fig. 72.

All streams flow in depressions. The small depressions which carry off rain-water from slopes just after a shower are *gullies* (Fig. 74). *Ravines* are depressions of the same sort, but somewhat larger, and *valleys* are larger still

Just as the tiny streamlets unite with one another to form creeks and these join to make rivers, so the gullies in which the smallest temporary streams flow, often unite to form wider and deeper gullies (Fig. 75). These, in turn, join one another to make ravines, and ravines lead to valleys. Valleys, like streams, usually end at the ocean or a lake; but in some cases, especially in arid regions, they end on dry land (Pl. IV). Large streams generally flow in large valleys and small streams in small valleys, but to this general rule *there are some exceptions*.

PLATE IV



Streams disappearing in the sand, gravel, etc., at the base of a mountain in an arid region. Scale about 4 miles per inch. (Paradise, Nev., Sheet, U. S. Geol. Surv.)

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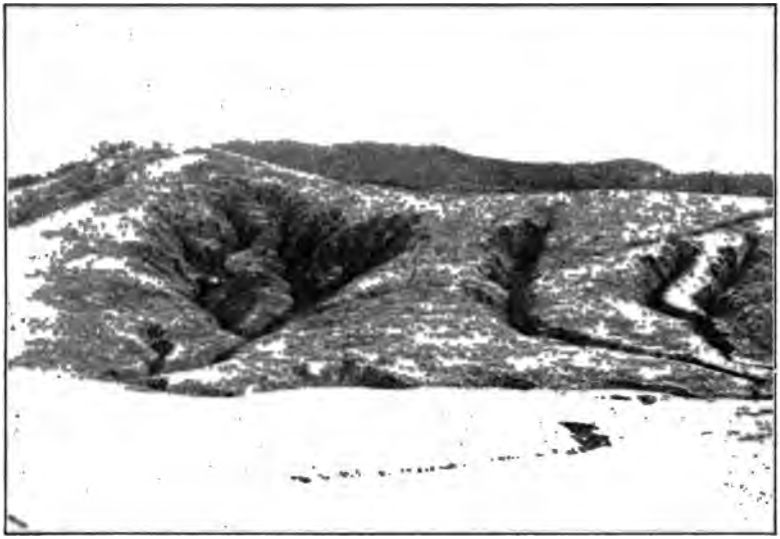


Fig. 74.—Gullies on slope above a valley flat. (Fairbanks.)

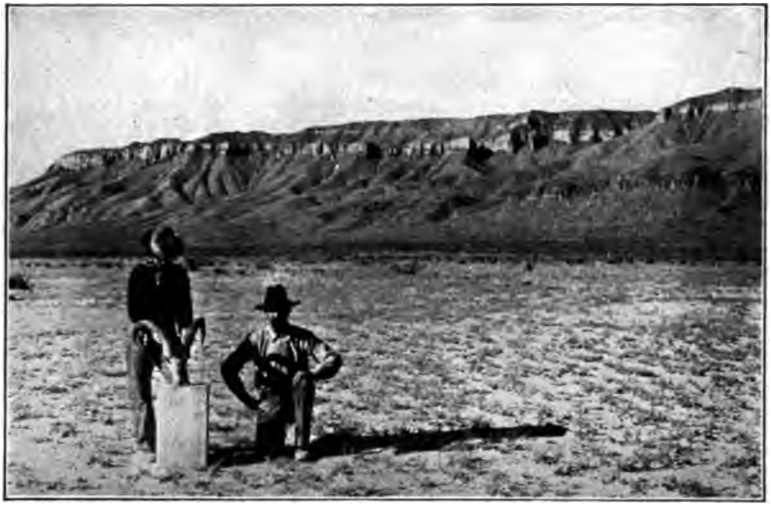


Fig. 75.—Sierra Diablo scarp, 25 miles from Van Horn, Texas. Numerous gullies are shown on the slope, the smaller ones of the upper part uniting into larger ones below. The figure also shows layers of unequal hardness The vertical faces of rock represent the harder layers. (U. S. Geol. Surv.)

THE EROSIVE WORK OF STREAMS

Streams carry sediment down their valleys. This may be readily seen when rivers are in flood, for at such times they are usually muddy; but besides the mud which is in the water, streams roll sand, gravel, etc., along their bottoms. The movement of the fine sediment in the stream, and of the coarse sediment at its bottom, may be seen in any little current along the roadside after a shower, and the great Mississippi carries its load in the same way. Streams carry some sediment, even when not in flood. Some of them have so little mud that their waters are clear, while others, like the Missouri and the Platte, are always turbid; but even clear streams often roll gravel and sand along their channels. Since most rivers run to the sea, much of the sediment which they carry finally reaches the ocean and is deposited there, especially near the shores.

The amount of material which certain streams carry to the sea has been carefully estimated. For a given river, the estimate is made by calculating the number of gallons or the number of cubic feet of water discharged by it each year, and then determining the average amount of sediment in each gallon or each cubic foot. It has been estimated that the Mississippi River carries to the Gulf of Mexico more than 400 million tons of sediment each year. This is an average of more than a million tons per day. It would take nearly 900 daily trains of 50 cars each, every car loaded with 25 tons, to carry an equal amount of sand and mud to the Gulf. All the rivers of the earth are perhaps carrying some 40 times as much as the Mississippi.

We have seen already that ground-water dissolves rock slowly, and that springs bring some of this dissolved matter to the streams. In addition to sediment, therefore, streams carry mineral matter in solution. These dissolved substances are commonly invisible, and, unlike mud, remain in the water even after it has become quiet. Their presence may often be shown by evaporating the water, when they are left behind. The amount of matter carried to the sea in solution each year, by all the rivers of the earth, has been estimated at nearly 5,000 million tons. This is about one-third as much as the *sediment* (mud, etc.) carried by the rivers.

These general facts show that the rivers are constantly shifting solid matter from the land to the sea. This is, indeed, their great work. Even the water which falls on the land, but does not flow directly to the sea, helps to make the rock decay (p. 68), and so prepares it for removal by running water. It may therefore be said, that *every drop of water which falls on the land has for its mission the getting of the land into the sea.*

Gathering sediment. As the rain-water flows down the slopes on which it falls, it picks up and carries along particles of soil and weathered rock. Many of them are carried to the streams to which the water flows. The amount of sediment which the stream gets in this way is large, if the immediate run-off flows over cultivated fields whose slopes are steep. The water which flows over slopes well covered with vegetation, such as pasture land or forest, carries away little soil, because the roots of the vegetation help to hold it. Gullies or "washes" often develop in plowed fields which lie on slopes, when other fields which are not tilled do not suffer in the same way. In some parts of France, all the soil on hill slopes and mountain slopes has been washed away since the people began to cultivate the land. Little dams have now been made in some of the ravines and valleys, to check the flow of water and the removal of soil (Fig. 76). In the southern part of our own country and elsewhere, slopes which were once covered with good soil have become barren because the soil has been washed away. The water flowing down a slope may flow as a sheet of water, or it may be gathered into streamlets. It carries more mud, etc., when it is gathered into streamlets, because such water runs faster. It is where the water is gathered into streamlets as it runs down the slope that little gullies are washed out (Fig. 74).

The stream in the valley not only carries away much of the sediment which is brought to it by the sheet-wash and by temporary streamlets from the slopes above, but it gathers more sediment from its bed and banks. This is true, for example, wherever the bed of a stream is composed of loose material, for particles of such material are easily loosened, and moved along in the current.

The sediment moved by a stream, whether in suspension or at the bottom, is its *load*. A stream is loaded when it has all the sediment it can carry; it is but partially loaded when it is carrying less than it might.

The stream does not gather load from its bed merely by the force of the forward movement of the water. A stream is not a single, straightforward current. When water runs through an open ditch or gutter, some of it may be seen to move from the sides to the center, and some from the center to the sides, while eddies are common. These lesser currents in the main current are especially *distinct where the* stream is swift. A swift river, too, "boils" and

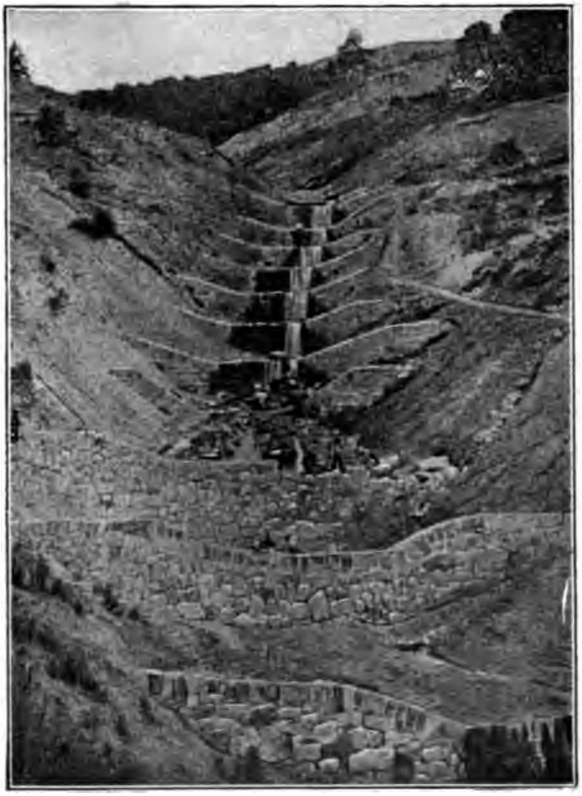


Fig. 76 —Shows the method of restraining the water of mountain torrents, to prevent the carrying away of the soil. Savoie, France (Kuss.)

eddies (Fig. 77), often in a striking manner. In the swift Columbia, for example, eddies are often so strong that it is difficult to row through them. In such a current, objects are often "sucked under" and brought up again. There are similar movements, though less readily seen, in slower streams.

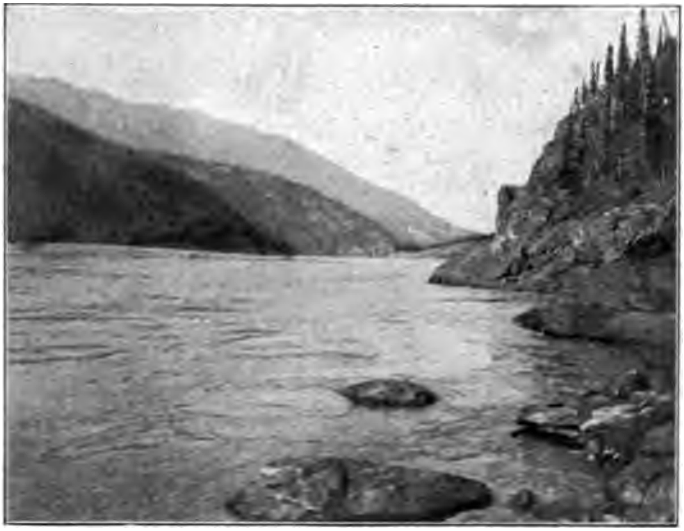


Fig. 77.—A "boiling" or eddying stream. Woods Canyon, Alaska. (U. S. Geol. Surv.)

All these phenomena show that there are numerous subordinate currents in the main current of a river, and that they move in various directions. Many of them are caused by the unevenness of the bed of the stream (Fig. 78). The subordinate upward

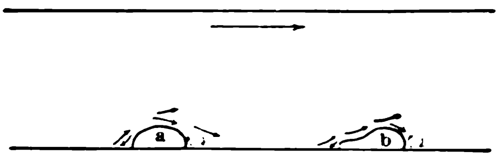


Fig. 78.—Diagram to illustrate the effect of irregularities, *a* and *b*, in a stream's bed, on the current striking them.

currents frequently carry sediment up from the bottom of the stream, bringing it into suspension, and when they strike the sides or bottom of the channel, they often wear off bits of loose matter

It might seem that swift streams should always be muddy, and slow ones always clear, for the minor currents are much stronger in swift streams than in slow ones; yet many swift streams, especially in the mountains, are remarkably clear. The reason is not far to seek. Even a swift stream is clear, (1) if immediate run-off and tributaries bring it no sediment, and (2) if the materials of its own bed are so coarse that it cannot pick them up. The clearness of many swift mountain streams is due to the fact that there is no fine material of any sort in their beds or banks, while the muddiness of some sluggish streams, such as the Lower Missouri and the Platte, is due, at least in part, to the fact that their bottoms and banks are of such fine, loose material that even their slow currents can get it and carry it forward. A river which picks up and carries away material from its valley, makes its valley larger.

Some river valleys are in solid rock, even in rock which is very hard (Fig. 79). Do rivers gather load from such valleys?

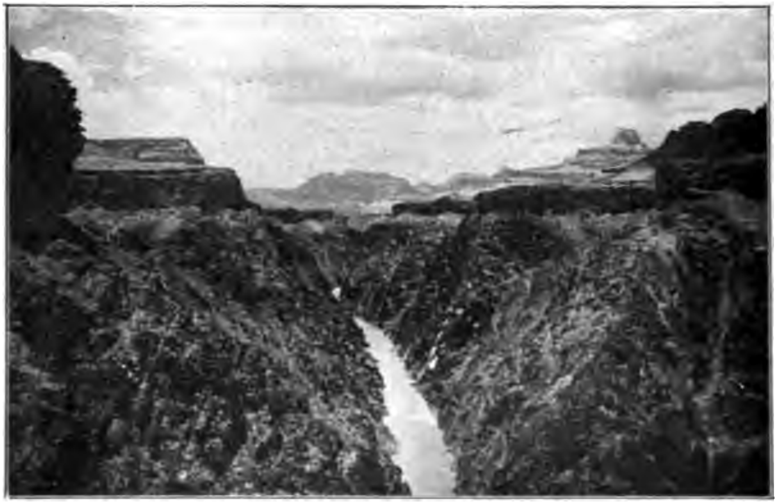


Fig. 79.—Grand Canyon of the Colorado (Peabody.)

In answering this question, we must remember, in the first place, that rock exposed to water, as in the bed of a stream, decays (p. 68). As it decays, it crumbles, and the crumbled part is readily swept away by a swift current. Again, the sand and gravel rolled along by a stream (Fig. 80) wear its bed, even if it is of hard rock. The sediment which a stream carries, therefore, becomes a collection of tools, with which the running water works, and with these tools even hard rock is slowly worn away. The rock in which valleys are cut is sometimes broken by many cracks or joints (Fig. 81), and in such cases the stream may carry away the pieces if they are not too large.

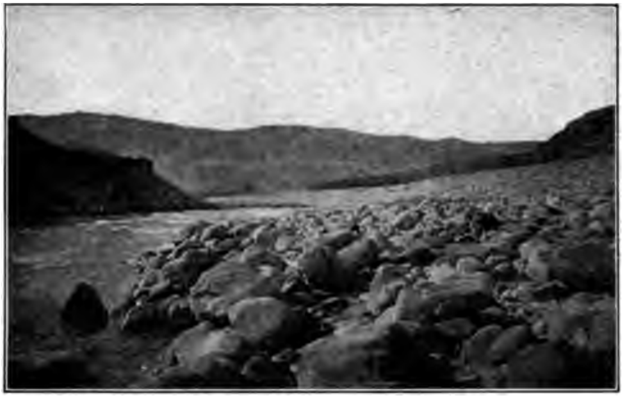


Fig. 80.—Tools with which a river works. These cobble-stones and small bowlders were brought down by the stream in flood, and left where they now appear. Other similar materials now in transit cause the ripples in the current. Chelan River, Wash., just above its junction with the Columbia. (U. S. Geol. Surv.)

Clear water, flowing over a bed of firm, hard rock, effects little mechanical wear. This is well shown in the case of clear streams like the Niagara. Tiny plants, similar to those which make moist stone walls green, may sometimes be seen growing on the limestone of its bed, where the water is shallow enough to allow the bed to be seen. This is the case even at the brink of the falls, where the current is very swift, but where all the force of the mighty torrent is unable to sweep these tiny plants away. If the stream had a partial load of sand or mud, these little plants would be worn away in a hurry. The sediment carried by a stream, therefore, helps it to erode, especially where the bed is of solid rock.

Carrying sediment. Streams carry sediment in more ways than one. As already stated, coarse materials, such as pebbles, are generally rolled along the bottom, while fine materials, such as particles of mud, are often carried *in suspension*, that is, in the water, above its bottom. The movement of the coarse materials rolled along the channel is easily understood, but the behavior of the fine sediment in suspension needs explanation.

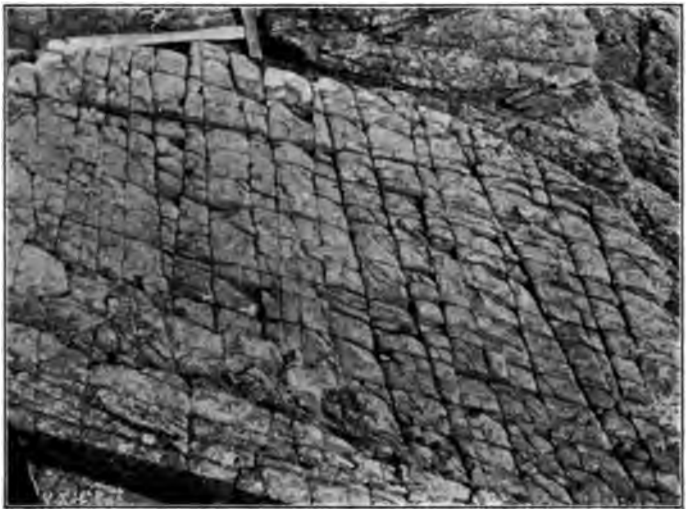


Fig 81.—Joints in bed rock. Pieces of the rock broken in this way may be picked up by a strong current and carried away. Currarie Port, South Ayrshire, Scotland. (H. M. Geol. Surv.)

Mud is composed chiefly of tiny particles of rock, nearly three times as heavy as water; yet these particles, heavy as they are, often remain in suspension for long periods of time. They are held up in the water much as dust is held up in the air. Since they are heavier than the water, they tend to sink all the time. They do in fact sink; but as gravity brings them down, many of them are caught by minor *upward* currents (Fig. 78), and so are carried up in spite of gravity.

It is chiefly by means of these minor upward currents in the main current that sediment is kept in suspension. The particles of sediment suspended in a stream are dropped and picked up again repeatedly, and the long journey of any particle is made up of many short ones. Particles of mud carried from Dakota to the Gulf of Mexico ordinarily make many stops in every state along the route, and the time consumed in their journey is generally many times as long as that taken by the water which started them.

Amount of load. The amount of sediment a stream carries depends on (1) its swiftness, (2) its volume, and (3) the amount and kind of sediment which it can get. Swift and large streams can carry a heavier load than slow and small ones.

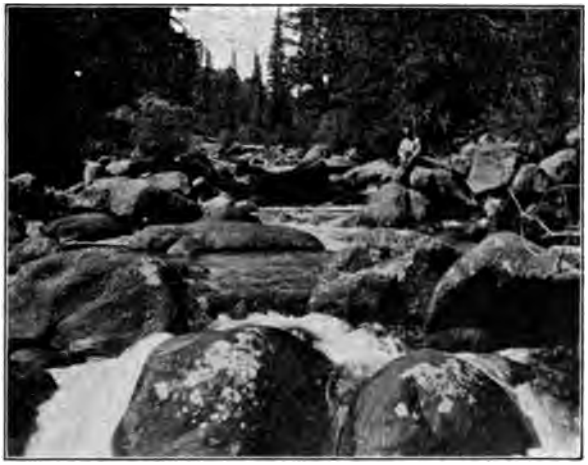


Fig. 82.—A stream channel clogged with bowlders too big for the stream to move, except in times of flood; Bighorn Mountains. (Hole.)

The effect of velocity on the carrying power of streams may be seen in most creeks and rivers which are wider in some places and narrower in others. Where the channel is narrow the current is swift, and here, in many cases, all fine material has been swept away, leaving only pebbles and larger stones (bowlders) in the channel (Fig. 82). Where the channel is wider, on the other hand, the bottom of the same stream may be covered with sand or mud.

By narrowing the channel of the Mississippi by making jetties near its mouth, in 1875, James B. Eads not only prevented further deposition of sediment there, but forced the river to clear out its own channel. This change permitted ocean vessels to reach New Orleans, and insured the commercial prosperity of that city.

Erosion defined. The wearing away of the land surface is erosion. In general, erosion consists of three more or less distinct processes. These are (1) the loosening of the rock, often by *weathering*, (2) the *picking up* of the loosened material, and (3) its *transportation*. When the running water is no longer able to carry away sediment, it ceases to erode its bed.

Deposition a necessary result of erosion. When the velocity of a stream is checked, it generally drops some of the sediment it was carrying. This is always the case if it had as much sediment as it could carry before the velocity became less. Some of the sediment is left in the valleys, especially toward their lower ends; and some of it is carried to the sea, or to the lake or other basin to which the river flows. Deposits of sediment in valleys build up (*aggrade*) their bottoms. Thus the Mississippi is spreading sediment over the bottom of its valley for hundreds of miles north of the Gulf of Mexico; and many other large streams, like the Nile, the Hoang Ho, and the Ganges, are doing the same thing. The total amount of sediment deposited on low land by running water is, however, far less than the amount worn away from the higher lands.

Changes Made by Rivers in their Valleys

A valley has three dimensions, depth, width, and length, and each dimension is subject to change.

The deepening of valleys. Swift streams make their valleys deeper, but many slow streams deposit more sediment than they take away, and so make their valleys shallower. Many streams deepen their valleys in their upper courses where their waters are swift, while they make them shallower in their lower courses where the currents are sluggish.

The principal reason why a stream is swift is that its channel has a steep slope; but as such a stream deepens its valley, the slope *or gradient of its channel* becomes less, and the stream flows more and

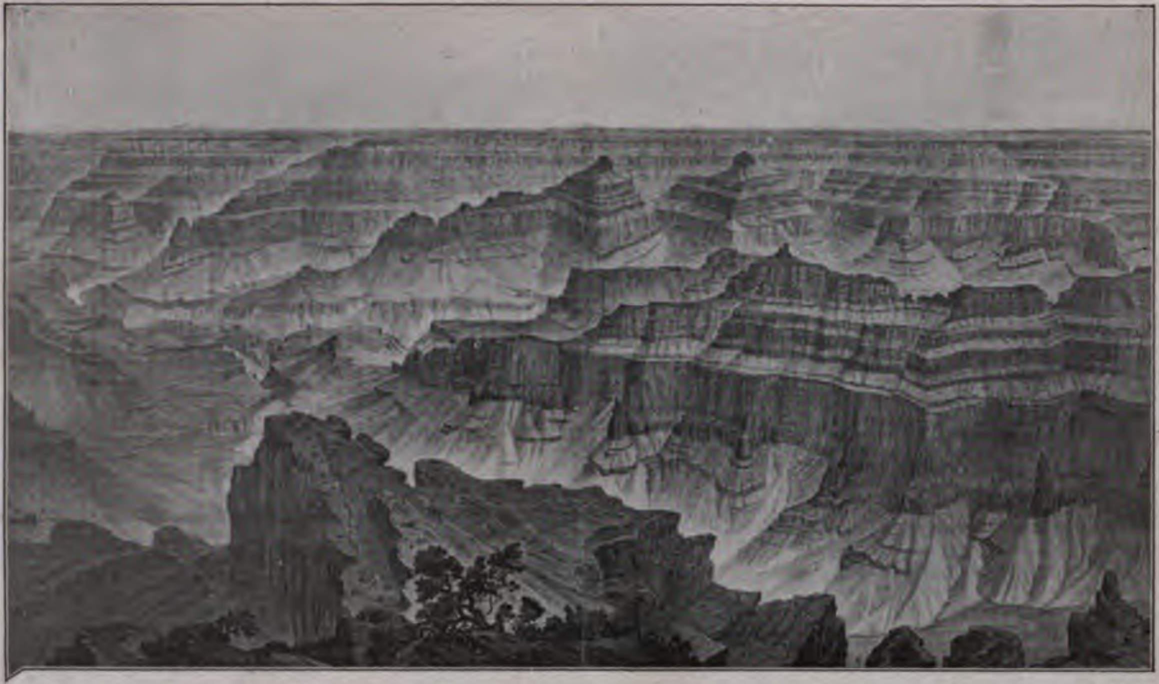


Fig. 83.—Sketch of a part of the Grand Canyon of the Colorado. A glimpse of the river is to be had at the left. Compare with Fig. 79. (Holmes, U. S. Geol. Surv.)

more slowly. *In time, every swift stream will cut its channel down until its current becomes sluggish.*

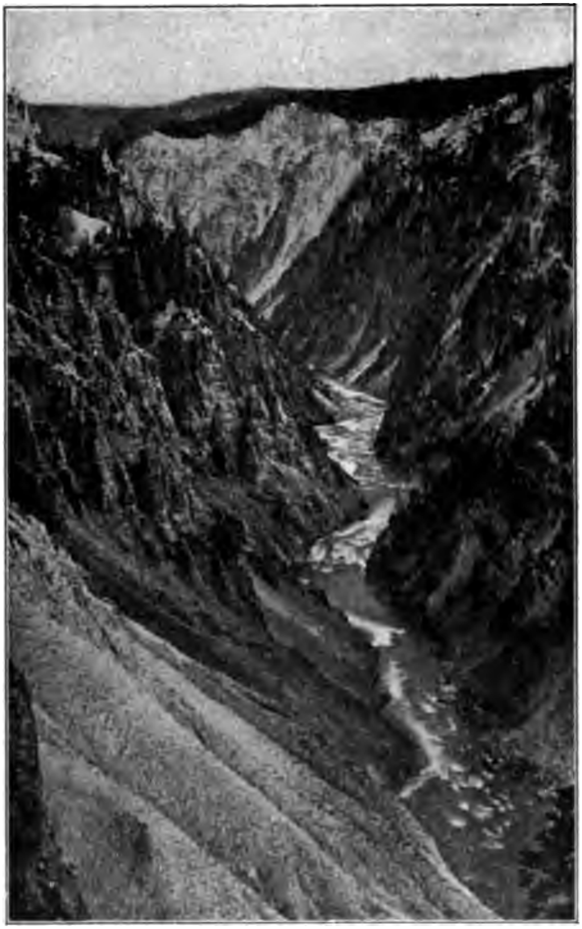


Fig. 84.– The Canyon of the Yellowstone below the Falls. Yellowstone National Park.

The depth which a valley may reach depends on the height of the land in which it is. The higher the land, the deeper the valley *may become.* Such valleys as the canyons of the Colorado (Figs

79 and 83) and the Yellowstone (Fig. 84) are never found in plains, but are characteristic of high lands; that is, of plateaus and mountains. The depth which a valley may reach depends also on its distance from the sea, by the route which the water follows. Thus if a stream flows from a plateau 2,000 feet above the sea and 200 miles from it, by a direct course, it has an average fall of 10 feet per mile; but if it runs off a plateau of equal height 2,000 miles from the sea, the stream has an average fall of but one foot per mile. If the volume of the stream is the same in the two cases, the valley in the plateau nearer the sea will become much deeper than the other.

Valleys near the borders of continents are therefore likely to be deeper than those in the interiors of continents, in lands of the same elevation.

Depth-limit. At its lower end, a stream cuts its channel down about to the level of the lake, sea, or other river into which it flows. *The level of the body of water into which a river flows therefore determines the level of its channel;* but a valley reaches the level of the water to which it leads only at its lower end. Its upper part is always higher.

The widening of valleys. If the growth of a valley were due merely to the down-cutting of the stream, the valley would be no wider than the stream which flows through it (Fig. 85). Since most valleys are very much wider than their streams, something besides the down-cutting of the streams must help along their growth.

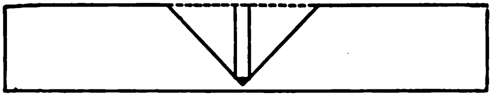


Fig. 85.—Diagram of a valley, the top of which is ten times the width of the stream.

The widening of valleys is brought about in many ways, among them the following:

(1) A stream sometimes flows against one side of its channel with such force as to under-cut the slope above (Pl. V and Fig. 86).

Slow streams are more apt to widen their valleys in this way than swift ones, because they are more easily turned against their banks by obstacles in the channel.

(2) Again, the rain-water flowing down the slopes of a valley carries mud, sand, etc., with it. This also widens the valley, by slowly wearing back its slopes.

(3) The loose earthy matter which lies on the slopes of a valley creeps slowly downward. If it is clayey, it becomes slightly fluid when wet, and in this condition tends to move slowly down the slope. Downward creep is brought about in other ways also.

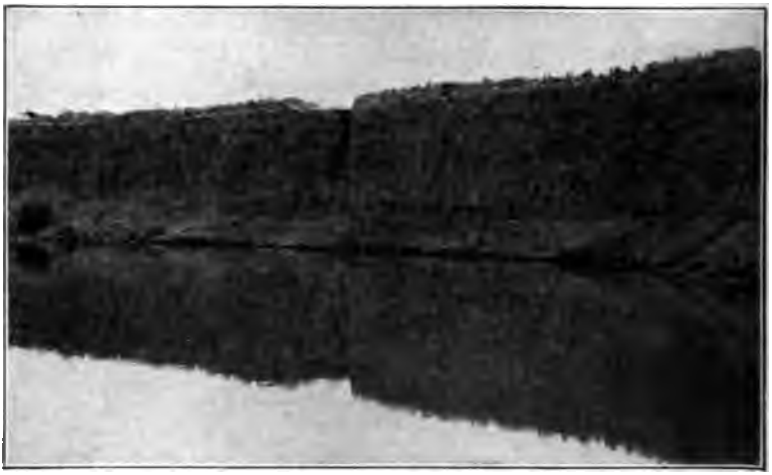
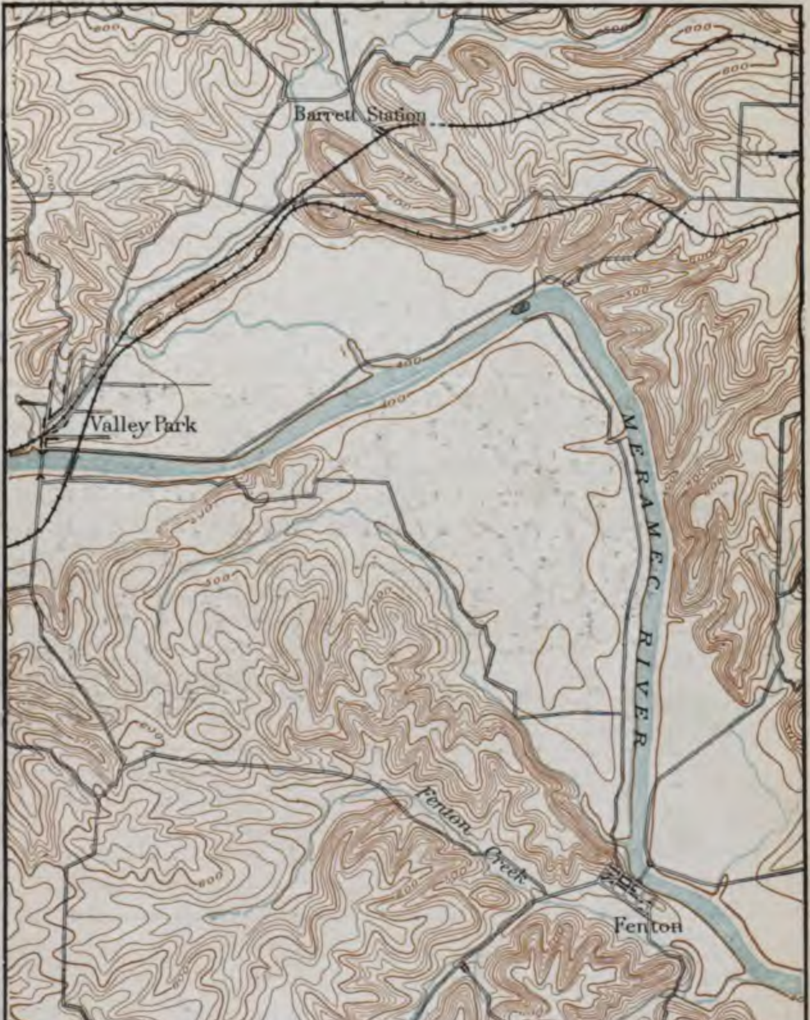


Fig 86. –The Colorado River flowing through the Imperial Valley of southern California, and under-cutting its bank, 1906. (U. S. Geol. Surv.)

(4) When the loose material of a steep valley slope is filled with water, as after a long rain, or when snow melts, it may slide or *slump* from higher to lower levels (Fig. 59).

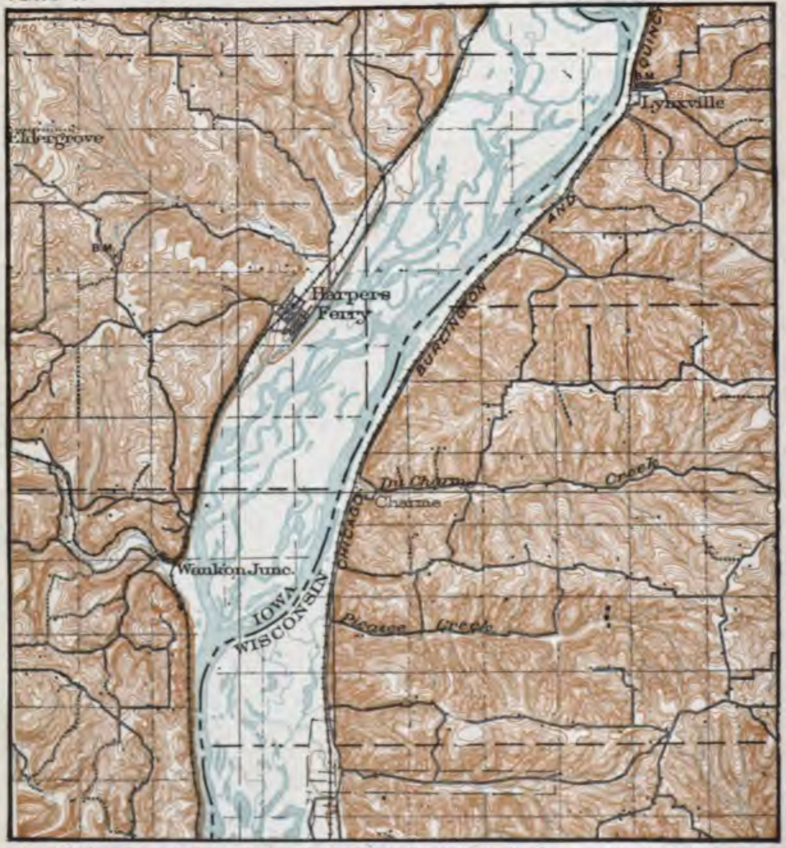
(5) Every animal which walks over the slope of a valley loosens more or less material if the slope is steep, and if this material moves at all, it is likely to move downward. Burrowing animals of all sorts loosen the surface material, so that it may work down the slope or be blown away. This, too, helps to widen the valley.

(6) Whenever trees which grow on the sides of valleys are



A stream widening its valley by lateral planation. Scale about 1 mile per inch. (U. S. Geol. Surv.)

PLATE VI



A well-developed river flat. Valley of the Mississippi, near Prairie du Chien, Wis. Scale about 2 miles per inch. (Waukon, Ia.-Wis., Sheet, U. S. Geol. Surv.)

overturned, they disturb more or less soil, some of which is likely to roll down.

(7) Fine material on the slopes of valleys is often blown away.

These and various other processes help to loosen rock or soil on the slopes, and prepare it for descent, and the descent or removal of matter from the slopes of a valley always increases its width. *All valleys, therefore, are being widened all the time.* In most processes of widening, the stream itself is an important factor, for it sooner or later carries away most of the material which descends to the channel. Along the bases of the slopes of many valleys there is much debris (*talus*) waiting to be carried away (Fig. 87).

Width limit. As a result of all the processes which wear back their slopes, valleys may become very wide. The widening of adjacent valleys may indeed go on until the high land or divide between them becomes very narrow (Fig. 88), or even until it is worn away altogether.

Valley flats. After streams have cut their valleys down to low gradients, they make flats, or *flood plains*, in their bottoms (Pl. VI). These flats are always below the level of the surface in which the valley lies. The Mississippi River at Dubuque has a flat

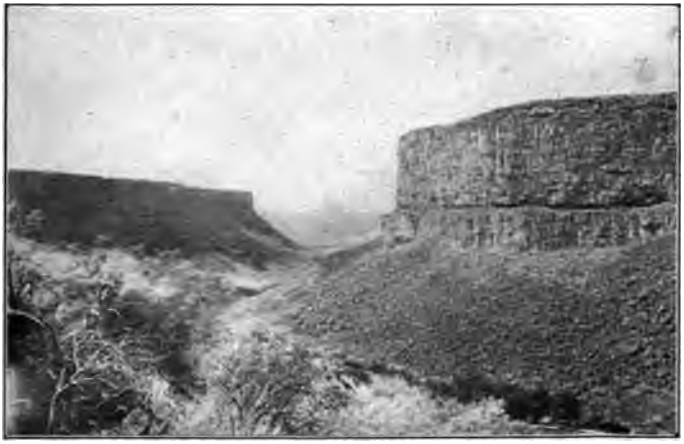


Fig. 87.—Talus at base of valley slope, ready to be carried off by the stream. Little Canyon — looking south into Snake River. (U. S. Geol. Surv.)

between one and two miles wide, and about 600 feet above sea-level. Near St. Louis the flat is 10 miles wide, and about 400 feet above sea-level. At Memphis it is about 35 miles wide, and but 220 feet above sea-level. At Vicksburg it has a similar width, and a height of but 90 feet. In general the flats of valleys increase in width down stream.

In conclusion, we may say (1) that rivers tend constantly to get the material of the land into the sea; (2) that in working to this end they develop flats below the general level of the surface in which the valleys lie; and (3) that these flats are usually wider and lower near the sea, and narrower and higher far from it. Pl. VI and Figs. 89 and 90 show valley flats in various sorts of regions.

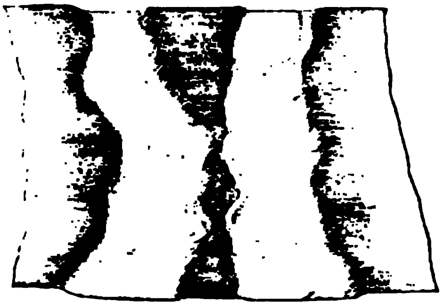


Fig. 88.—Diagram showing streams in adjacent valleys, under-cutting the divide between them. They may, in time, destroy the divide by lateral planation.

The streams which flow through flat-bottomed valleys are generally slow and winding, and are said to meander (Pl. VII, and Fig 2 of Pl. X). A meandering stream often flows against the base of the slope of its valley, and wearing it, drives it back (Pl. V). This makes the valley flat wider. Most valley flats are developed chiefly by the side-cutting of the streams.

The lowest level to which a stream can lower its flat is *base-level.* Any valley flat is a sort of base-level, though the first one developed by a stream is not necessarily the lowest level to which it may bring its valley bottom. *It is the lowest level to which it can bring its valley under the conditions which exist when the flat is made.*

PLATE VII

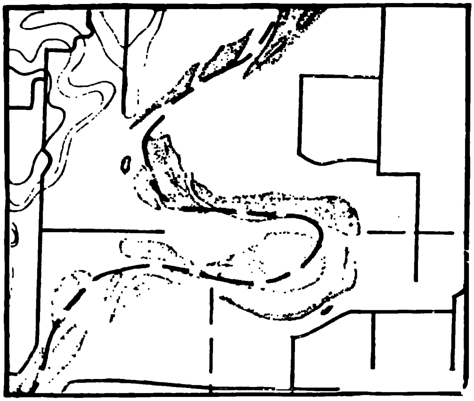


Fig. 1.—A meandering stream. The Missouri River. Scale about 2 miles per inch. (Marshall, Mo., Sheet, U. S. Geol. Surv.)

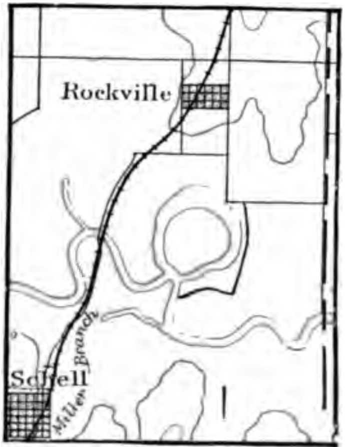


Fig. 2.—A further stage in the development of a meander. Scale about 2 miles per inch. (Butler, Mo., Sheet, U. S. Geol. Surv.)

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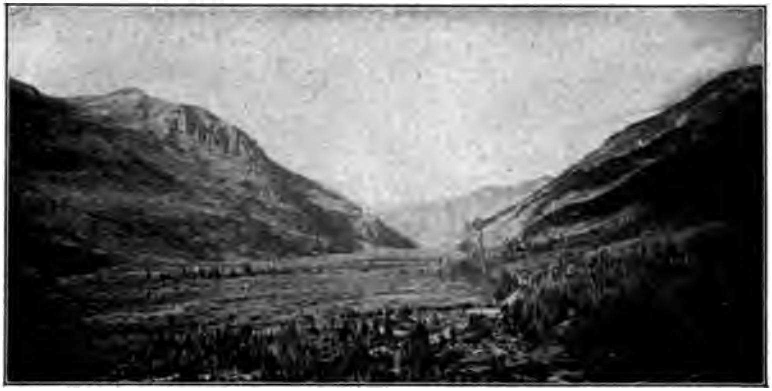


Fig. 89.—A valley much older than that shown in Fig. 84; Gray Copper Gulch, southwestern Colorado. (U. S. Geol. Surv.)

It is, therefore, a *temporary base-level.* Later, under changed conditions, the stream may sink its channel below its first flat. When this is done by a main stream, all its tributaries may do the same.

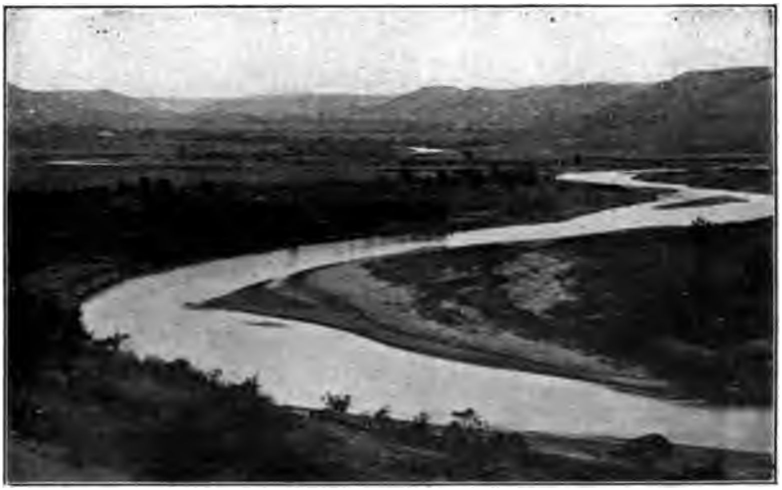


Fig. 90.—A wide valley flat. Milk River, near Pendant d'Oreille, Canada. (U. S. Geol. Surv.)

The lengthening of valleys. Valleys are lengthened, too, in various ways. One way is illustrated by the gullies developed on hillsides during heavy rains. The gully made during one rainstorm (Fig. 91), is often lengthened at its upper end during the next, by the water which flows in at its head. This process of lengthening may sometimes be seen even during the progress of a

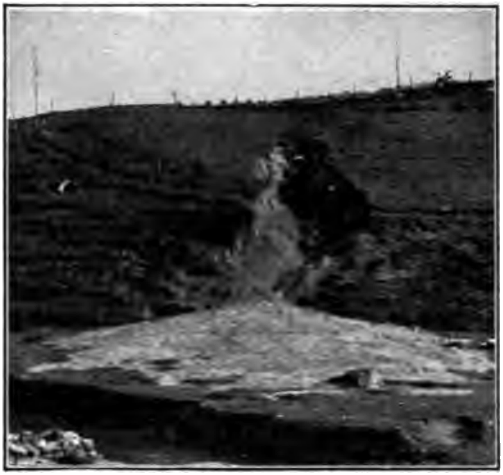


Fig. 91.—A gully developed by a single shower. (Blackwelder.)

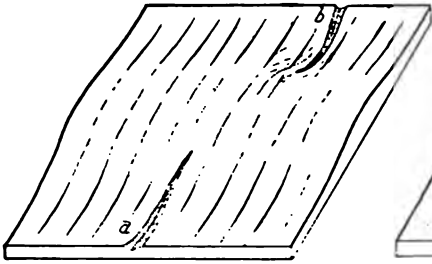


Fig. 92.

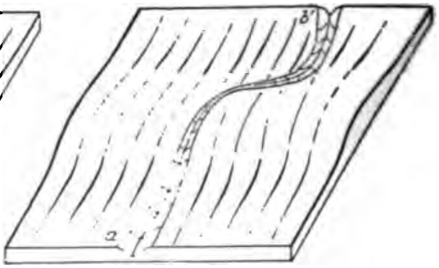


Fig. 93.

Fig. 92.—Two young valleys heading toward each other.
Fig. 93.—Valleys of Fig. 92 developed headward until their respective heads *have met, and the* divide has been lowered a little at the point of meeting.

single storm. The heads of valleys often have the characteristics of ravines or gullies, and valleys are, in some cases, no more than grown-up ravines, whose heads are advancing after the manner of hillside gullies.

By this process, the head of a valley may advance until a *permanent divide* is established. Thus in Fig. 92 the heads of the valleys *a* and *b* may be worn back farther into the upland, but when the heads of the valleys reach the point shown in Fig. 93, neither can advance farther, *if the conditions of erosion are the same on both sides of the divide.* The divide is then permanent, for though continued rain fall may lower it, it cannot shift its position (Fig. 94).

Not all the valleys, however, are lengthened at their heads after the manner outlined. Thus the head of the St. Lawrence River is at the foot of Lake Ontario, and will remain there as long as the lake shore remains where it now is.

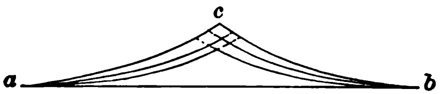


Fig. 94.—Diagram to illustrate the lowering of a divide without shifting it. The crest of the divide is at *c*, and at points directly below *c*, successively. If the erosion was unequal on the two sides the divide would be shifted. Letters *a* and *b* correspond with *a* and *b* of Fig. 92.

As it grows in length, the head of one valley may reach the lower end of another, when the two become one. Figs. 95 and 96.

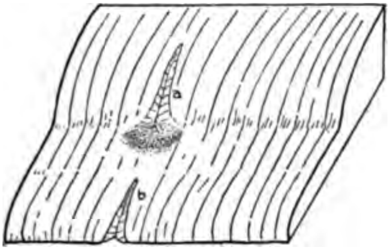


Fig. 95.

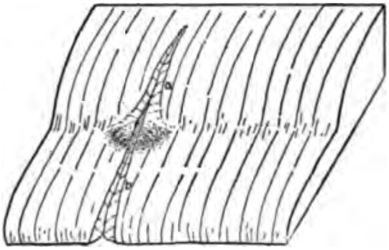


Fig. 96.

Fig. 95.—Two small valleys, *a* and *b*, have developed, the one on the steeper slope above, and the other on the gentler slope below.

Fig. 96.—Represents the two valleys of Fig. 95, further developed. *b* has grown until its head has reached the lower end of *a*, and the two have become one. The two figures represent one method by which valleys grow longer.

If one valley reaches another under the conditions shown by Figs. 97 and 98, and if the head of the valley *a* is lower than the valley it reaches, *b*, the valley *a* will steal the water which would otherwise flow down *b*. The valley of *a* is thus lengthened.

Streams are sometimes lengthened at their lower ends. This is the case where the sediment which they deposit at their lower ends builds the land out into the sea. The stream then finds its way across the new-made land.

Summary. All valleys are being made deeper in some places all the time; all valleys are being made wider all the time; and some valleys are growing longer. All streams sooner or later develop flats in their valleys, and these flats may increase in width till the divides between them become low, or even until they are worn away altogether.

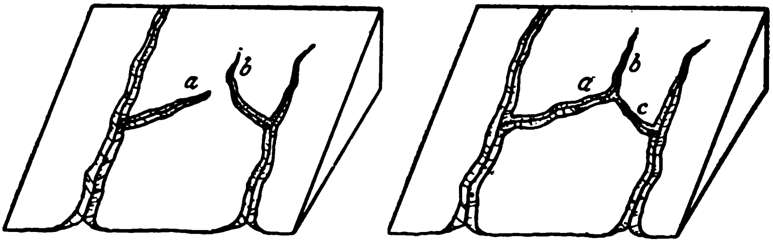


Fig. 97. Fig. 98.

Figs. 97 and 98.—Diagrams to illustrate a phase of piracy. By the **headward** growth of *a*, Fig. 97, it reaches *b*, and finally carries off its upper **waters**; *a*, Fig. 98, is a pirate; *b* Fig. 98, has been *diverted*, and *c* has been **beheaded**.

The History of Rivers and Valleys

Since valleys grow deeper, wider, and longer, year by year, they must formerly have been smaller than now. If we could trace them backward in their history, we should find that there was a time when the large valleys of the present day were small, when many of the small valleys were only ravines, when the ravines were only gullies, and when the present gullies did not exist. Or, going still farther back, we may imagine a time when even the large valleys had a beginning.

A principal method of valley birth and growth is illustrated by the development of a gully, already outlined. A gully started during one shower is made deeper, wider, and longer by the next. Year by year, as the result of repeated showers and repeated meltings of snows, the gully grows to be a ravine, and later a valley.

Not all gullies, however, become valleys. On a steep slope, many gullies may start (Fig. 75); but as they grow, some are so widened as to take in others (Fig. 99), and the number is reduced. But a small proportion of all that start become ravines, fewer still become small valleys, and the number of valleys which attain great length is very small. As valleys develop from gullies, the heads of some work back faster than others, with the result that many valleys are arrested in their development early, as shown in Figs. 100, 101, and 102. For example, *c*, Fig. 100, will grow in length little more, because the water which falls on the land above its head flows off by some other route to the sea. Later stages in the growth of the valleys shown in Fig. 100 are illustrated by Figs. 101 and 102.

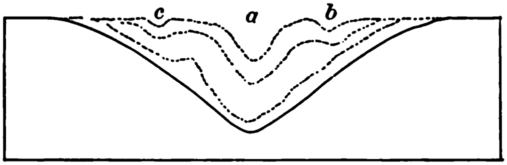


Fig. 99.—Diagram illustrating how one gully takes another as a result of lateral erosion.

The courses of valleys. The headward growth of a gully is due chiefly to the erosion of the water which flows into its upper end. If all the material about the upper end of the gully is equally hard, the head of the gully works back in the direction whence the most water comes (Figs. 103–105). But the head of the gully keeps advancing, and if the surface about its head is uneven, more water may flow in, now from one direction, and now from another. The result is that the head of the gully is rarely worn back in a straight line.

If the soil or rock about the head of a gully is harder at some points than at others, the head of the gully is likely to advance on that which is most easily worn. Inequalities of slope or material, therefore, *cause the head of a gully to turn now to one side, and now* to the other, as it advances, and where the head of the gully goes, there the valley which develops from it follows. The crookedness of many valleys is thus explained.

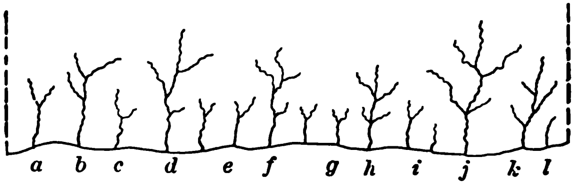


Fig. 100.—Diagram showing a series of young streams along a coast.

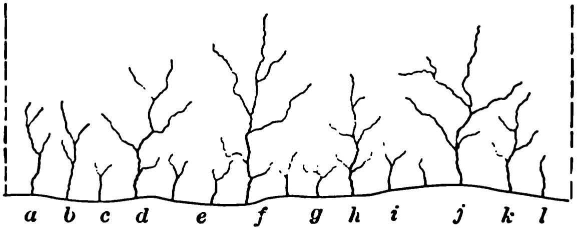


Fig. 101.—The same streams shown in Fig. 100, after a period of growth; *d*, *f*, and *j* have grown much beyond their neighbors.

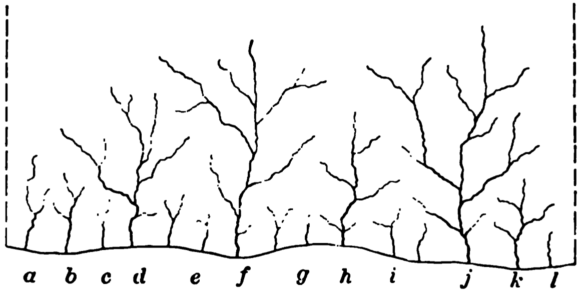


Fig. 102.—The same streams developed still further; *d*, *f*, and *j* have developed so far as to stop the growth of most of the others.

The permanent stream. Water commonly flows in gullies only when it rains and when snow melts, and for a short time afterward; but many valleys developed from gullies come in time to have permanent streams. Where does the water for the permanent stream *come from?*

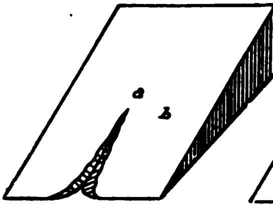


Fig. 103.—Diagram showing a young valley. If more water enters its head from the direction *b* than from any other direction, the head of the valley will be carried back toward *b*, as shown in Fig. 104.

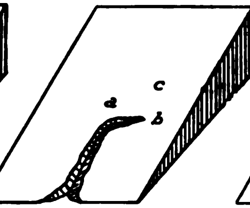


Fig. 104.—Shows the development suggested in Fig. 103. If more water now enters the head of the valley from the direction *c* than from any other direction, the growth of the valley will be as shown in Fig. 105.

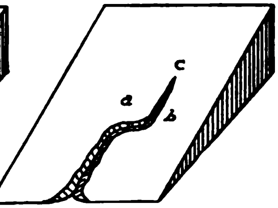


Fig. 105.—Shows the development suggested by Fig. 104. The head of the gully has advanced from *b* to *c*, and it will continue to advance in this direction so long as most water enters the head from the direction *c*.

When a valley has been deepened so that its bottom is below the ground-water surface, the ground-water seeps or flows out into the valley, and forms a stream. In Fig. 106, *a* represents the water surface in wet weather, and *b* the water surface in dry weather. The valley whose cross-section is shown by 1 would not have a stream derived from ground-water; the valley whose cross-section is represented by 2 would have a small stream in wet weather; while the valley 3 would have a permanent stream, because it is below the ground-water level of dry times. In regions where the ground-water surface is deep, the valley must be deep to get a stream. In regions where the ground-water surface is near the land surface, even shallow valleys may have permanent streams.

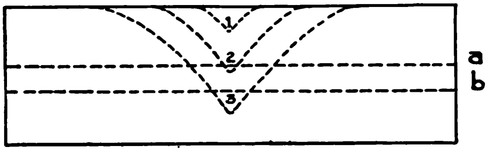


Fig. 106.—Diagram showing ground-water surface; *a* the ground-water surface at ordinary times, and *b* in times of drought. When a valley has been cut below *a*, there will be a stream in wet weather, but it will go dry in time of drought. When the valley is down to *b*, below the ground-water surface of dry weather, the stream will be permanent.

Streams which are fed by lakes, and streams which have their sources in snow and ice fields which last from year to year, do not depend on ground-water, though they often receive it.

Valleys are not all grown-up gullies. Not all valleys are formed by the growth of gullies. A vast area in the northern part of North America, for example, was once covered by a great sheet of snow and ice. The rivers which had existed in this area ceased to flow, for the most part, while the ice lay on the land. Many of their valleys were filled, at least in places, by the debris (*drift*) which the ice left when it finally melted. The result was that great areas were left without well-defined valleys. The melting ice, however, supplied great quantites of water, and this water flowed along the lowest lines of descent which it could reach. In this case, each stream began to cut a valley all the way from its head to its mouth at the same time. No part of such a valley is much older than another.

Valleys developed in this way may have permanent streams at the outset, since they do not depend on ground-water. The course of a valley developed in this way was determined by the direction which the water took at the outset. Again, the melting of the ice left many lakes on the surface of the land it had covered, and the rainfall of the region was great enough to make many of them overflow. When a lake overflows, the out-going water follows the lowest line of descent, and develops a valley in the way just outlined. In these ways, rivers were soon re-established on the surfaces from which the ice melted.

Growth of tributaries. Most valleys are joined by many smaller tributary valleys. The reason is readily understood. The material

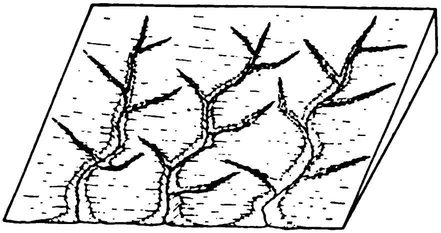
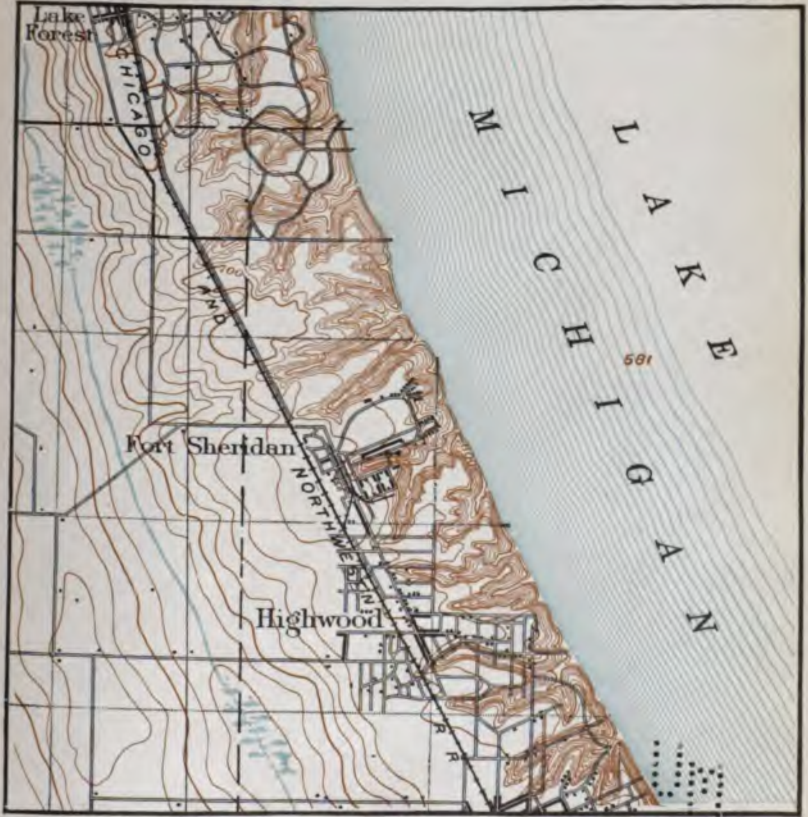
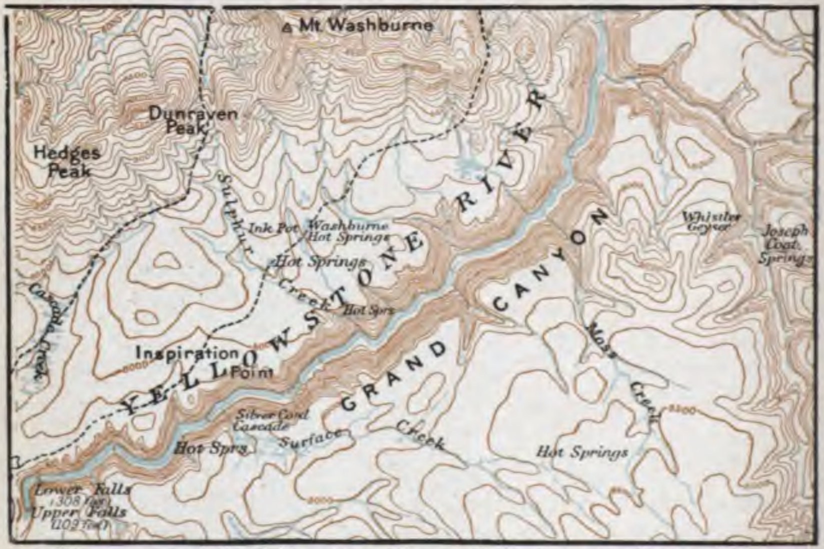


Fig. 107.—Diagram showing tributaries in an early stage of development.



Youthful valleys. Shore of Lake Michigan just north of Chicago. Scale about 1 mile per inch. (Highwood, Ill., Sheet, U. S. Geol. Surv.)

PLATE IX



The canyon of the Yellowstone River. Scale about 2 miles per inch. (Canyon, Wyo., Sheet, U. S. Geol. Surv.)

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of the slopes leading down to a valley bottom is often of unequal hardness, and the water flowing down wears the softer places more than the harder ones. Or again, the slopes are not smooth, and the run-off follows the lowest lines on the slopes. The erosion of the side slopes is therefore greater along some lines than others, and tributary gullies are started (Fig. 107). They grow in the same way, and for the same reasons, as the valleys from which they develop. In time, some of them become valleys, and have permanent streams. Tributary valleys develop tributaries, and the process goes on until a network of watercourses affects the surface. Figs. 72 and 108 show surfaces in this condition.

A valley and its tributaries constitute a *valley system.* A stream and its tributaries constitute a *drainage* or *river system,* and the area drained by a river system is a *drainage basin.* From the conditions under which a valley system develops, the outline of a drainage basin often comes to be rudely pear-shaped (Fig. 109).

Stages in the history of a valley. Valleys grow in size as they advance in years, as we have seen. When a valley is *young,* it is narrow, and its slopes are steep. If the land is high, it has a steep gradient, and soon becomes deep. Its cross-section is then somewhat V-shaped (Fig. 84), and its tributaries are short. The *mature valley* is wider (Figs. 89 and 90), its slopes are often gentler, and its tributaries are longer and older. An *old valley* is wide, and has a broad flat or flood plain, and a low gradient.

A stream also, as well as its valley, passes from youth to maturity, and from maturity to old age. In its youth, it is likely to be swift, unless it flows through low land. In maturity, it is much steadier in its flow, and when it reaches old age, it winds slowly through its wide plain. Even an old stream, however, may take on the vigor of youth when it is flooded.

The terms *youth, maturity,* and *old age* may be applied to river systems, as well as to single rivers. Every river system, aided by weathering, has entered upon the task of carrying to the sea all the land of its basin which is above base-level. So long as the river system has the larger part of its task before it, it is *young* (Pls. VIII and IX, and Figs. 79 and 84). When the main valleys have become wide and deep, and the areas of upland have been well cut up (dissected) by valleys, the river system is said to have reached *maturity* (Fig. 1, Pl. X, Fig. 89). When the task of base-leveling its drainage basin is nearing completion, the river system has reached *old age* (Fig. 2,

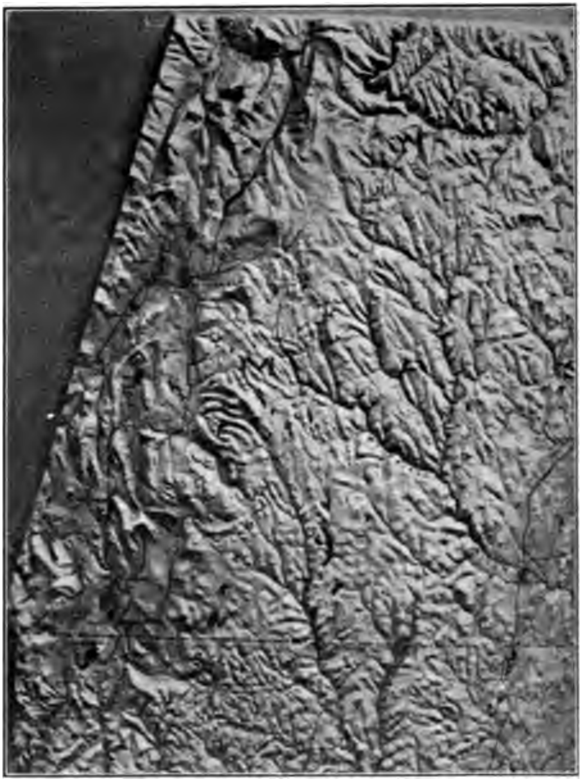


Fig. 108.—Photograph of a model (Howell) of an area in southwestern Mass and northwestern Conn.; a surface much dissected by erosion.

Pl. X). The master stream of a drainage system attains the characteristics of maturity and old age sooner than its tributaries, and in its lower course sooner than in its upper.

The topography of a drainage basin is youthful when its river system is youthful, mature when its river system is mature, and

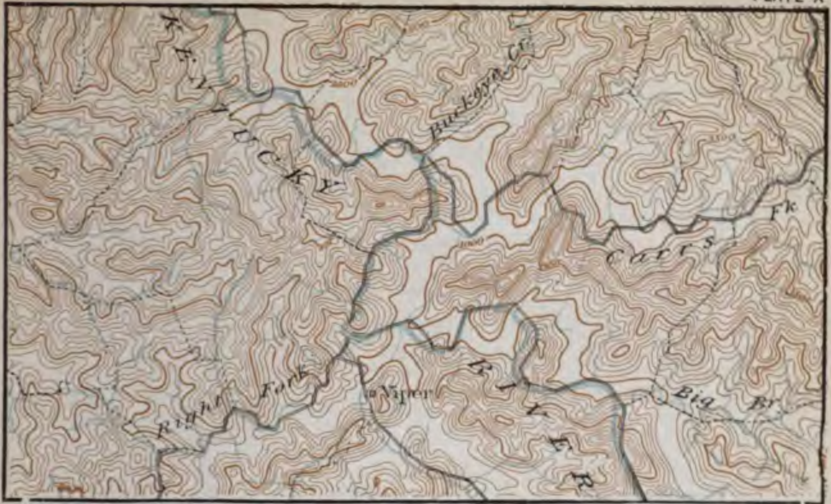


FIG. 1.—A region in a mature stage of erosion. Scale about 2 miles per inch. (Kentucky, U. S. Geol. Surv.)

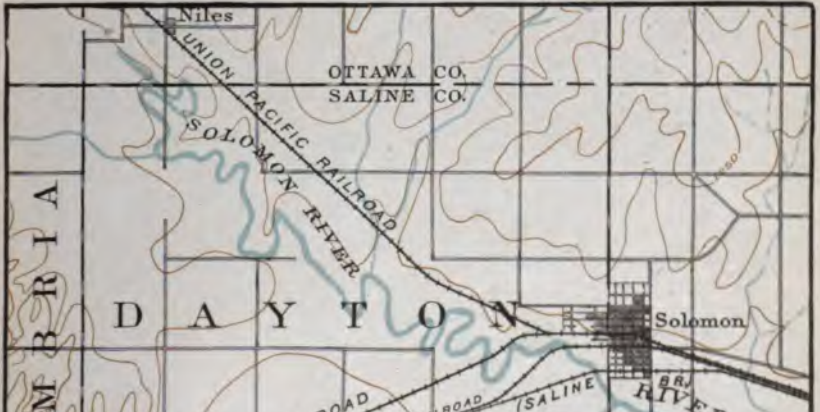


FIG. 2.—A plain in old age. Scale about 2 miles per inch. (Abilene, Kan., Sheet, U. S. Geol Surv.)

old when its drainage is old. In an area of *youthful topography* much of the surface has not yet been much changed by erosion (Fig. 107, Pls. VIII and IX), and the surface is often ill-drained. In an area of *mature topography*, the surface has been largely reduced to slopes by erosion (Fig. 108, Fig. 1, Pl. X), and the surface is well drained; while an area of *old topography* is one which has been brought down to general flatness by erosion (Fig. 2, Pl. X). Some parts of a drainage basin, especially those parts near the master stream, may take on the characteristics of age, while other parts farther from the trunk stream may not be advanced beyond maturity, or even youth.

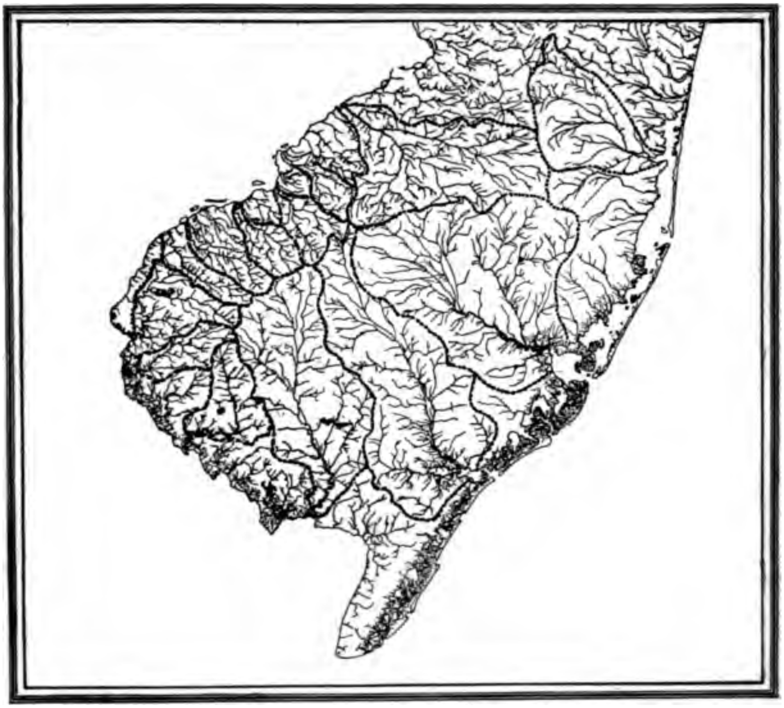


Fig. 109.—Map of the principal streams of southern New Jersey, with outlines of their basins shown in dotted lines.

Rate of Land Degradation

Since all lands are being cut down by running water, it is a matter of interest to know how fast this is taking place, and whether the lands are to be destroyed altogether.

It has already been stated (p. 78) that estimates have been made of the amount of mud, sand, etc., carried to the Gulf each year by the Mississippi River, the amount being about 7,500,000,000 cubic feet. This would be enough to cover one square mile to a depth of 268 feet. This amount of sediment, spread out uniformly over the basin of the Mississippi River system, would make a layer about $\frac{1}{400}$ of an inch thick, or a little more than $\frac{1}{5000}$ of a foot. If to this we add the material carried to the sea in solution, the rate of degradation of the Mississippi basin is about one foot in 3,500 years. This, perhaps, represents about the average rate at which the lands of the earth are being lowered by erosion at the present time. This rate of lowering is much exceeded by some rivers. It is estimated that the upper Ganges River is lowering its basin a foot in a little more than 800 years, and that the Po River is lowering its basin a foot in a little more than 700 years.

If the rate at which the Mississippi is degrading its basin were to be continued without interruption, and if nothing occurred to counteract it, the North American continent would be reduced to sea-level in about 7,000,000 years, for its average height is about 2,000 feet. It is certain, however, that the present rate of down-cutting cannot continue, for as the land becomes lower, the rate of erosion must diminish, since the water must then move more slowly. As a matter of fact, mechanical erosion by running water would cease when the surface was brought to base-level, though solution would still go on.

Other changes, to be discussed later, are likely to occur to prevent the land from being worn down to base-level. The continent is therefore likely to endure not only much longer than 7,000,000 years, but probably indefinitely. Nevertheless, these figures serve a useful purpose in indicating the rate of change which the land is undergoing as the result of the fall of rain and snow upon it.

Conditions affecting the rate of erosion. Some of the conditions affecting the rate of erosion by running water have been stated in the preceding pages, but they may be brought together at this point.

The rate at which running water wears down the surface over which it flows depends largely on (1) the volume and (2) the velocity of the water, on (3) the character of the material over which it flows, and (4) the amount and kind of load it carries.

1. The volume of water flowing over the land depends chiefly on the amount of precipitation.

2. The velocity of running water depends on (a) its gradient, (b) its volume, especially its depth, (c) its load, and (d) the shape of its channel. The higher the gradient, the greater the volume, the less the load, and the smoother and narrower its channel, the faster the flow.

3. If the surface of the land on which the rain falls is bare, solid rock, the immediate run-off brings little sediment to the stream; and if the bed of the stream is bare, solid rock, the stream wears it less than if it is of mud or sand.

4. To work most effectively, the stream must carry load (tools) enough to enable it to cut rapidly, but not so much as to retard its flow seriously, and keep it from using its tools vigorously.

Exceptional Features Developed by Erosion

Canyons and gorges. Valleys which are narrow and deep, but small, are often called *gorges*. Similar valleys of larger size are called *canyons*. The sides of gorges and young canyons are sometimes nearly vertical (Fig. 110), but the sides of the large canyons are rarely so. The distinction between a canyon and a valley which is not a canyon is not a very sharp one, and in regions where canyons abound, the term is often applied to all valleys.

The Colorado Canyon (Fig. 83) is the greatest canyon known. Its depth is about a mile. Though narrow at the bottom, it is eight to ten miles wide at the top. With a depth of one mile and a width of eight, the slope, if uniform, would have an angle of less than 15°. The cross-section of such a valley is shown in Fig. 111. But the slopes of the canyon are step-like (Fig. 112), a form which is the result of the unequal hardness of the rock of the canyon walls. The harder strata are the cliff-makers.

The Yellowstone River also has a great canyon about 1,000 feet deep (Fig. 84 and Pl. IX). It is narrower in proportion to its depth than the canyon of the Colorado. The Snake (Fig. 87) and the Columbia rivers have wonderful canyons in some parts of their courses, and so has the Arkansas River where it crosses the Rocky Mountains. The canyons of many smaller and less well-known rivers are almost equally striking.

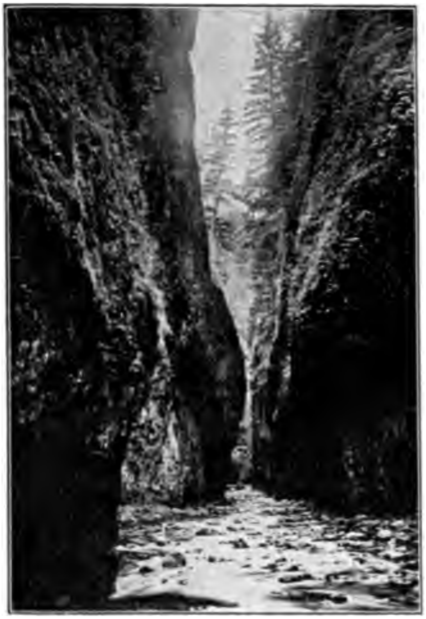


Fig. 110.—Oneonta Gorge, Canyon of the Columbia, Ore. (Fairbanks.)

A narrow valley means that the processes which have made it deep have outrun the processes which make it wide. Valleys are deepened rapidly when their gradients are high and their streams strong. They are widened slowly (1) when the climate is arid, so that there is little slope wash, (2) when the stream is so swift that *it does not meander*, and (3) when the material of the sides is such that it will stand with steep slopes. Solid rock, for example, will stand with steeper slopes than loose sand. We conclude, therefore, that (1) great altitude, (2) arid climate, (3) swift streams, and (4) rock which will stand in steep slopes favor the development of canyons. In other words, young valleys in plateaus and mountains are likely to be canyons. A strong stream in a dry region is possible when the stream is supplied with abundant water from a humid region above. The Colorado, Snake, and Arkansas rivers are examples.

The plateaus of the western part of the United States furnish the conditions which favor the development of canyons, and valleys of this type are there common. This is true both of main streams and of their tributaries.

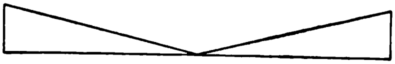


Fig. 111.—Diagram showing the proportions of a valley, the width of which is eight times the depth. These are approximately the proportions of the Colorado Canyon.

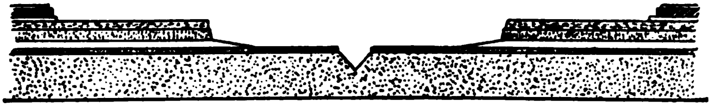


Fig.112.—Cross-section of the Colorado Canyon.

Canyons are sometimes developed where only a part of the conditions specified above are present. Thus the Niagara River has a gorge or canyon below the Falls (Pl. XI). Here the down-cutting is so rapid that the widening of the valley has not kept pace with it, in spite of the fact that the region has an abundance of rainfall.

The deeper canyons of the West make travel athwart their courses almost impossible, while their rivers rarely serve the needs of navigation or irrigation. The ancient cliff-dwellers often made their homes in the recesses of canyon walls (Fig. 113), probably because these positions could be easily defended against enemies.

Canyons must finally become valleys of another type, for the stream in the canyon will in time cut to base-level. The valley will then stop growing deeper, but widening will still go on, and the narrow valley will become so wide that it will cease to be a canyon.

Bad lands. The name *bad land* is sometimes given to the type of topography shown in Figs 75 and 114. Such topography is developed in the late youth or early maturity of certain high regions, and is found in various parts of the West, especially in western Nebraska, Wyoming, and the western parts of the Dakotas, where the formations are largely sandstone or shale, alternating with beds of clay. Climatic factors are also concerned in the development of bad land topography. A semi-arid climate, where the rainfall is much concentrated, seems to be most favorable.

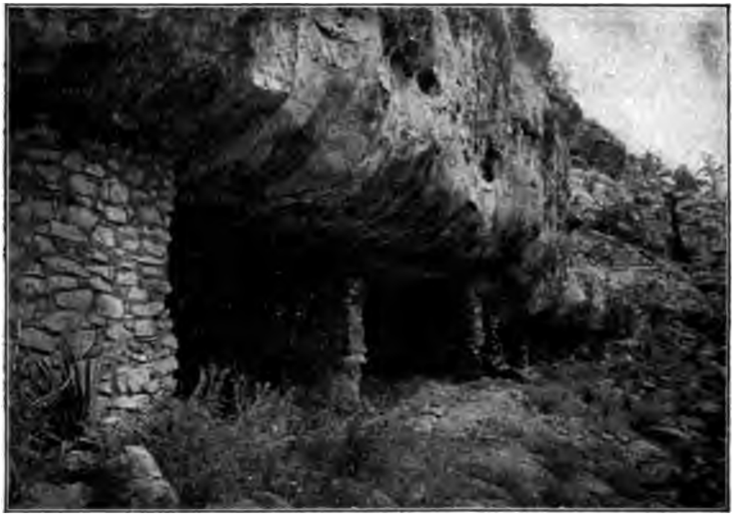
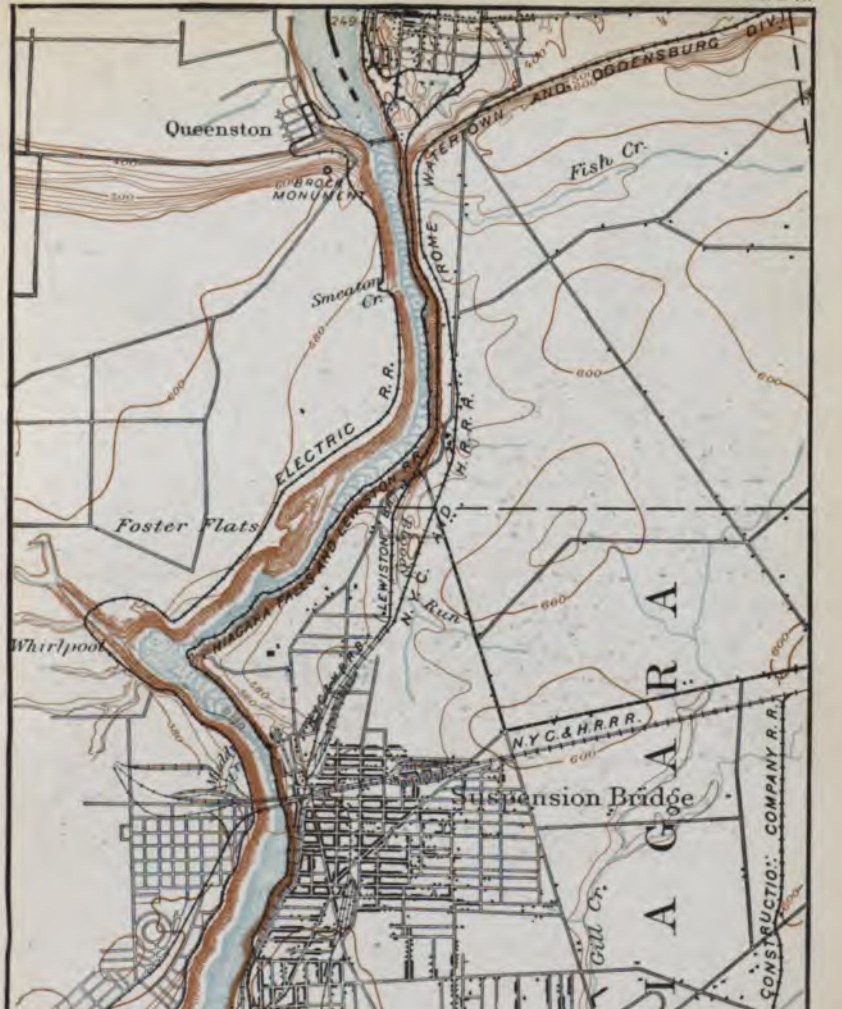


Fig. 113.—Cliff dwellings: southwestern Colorado. (White.)

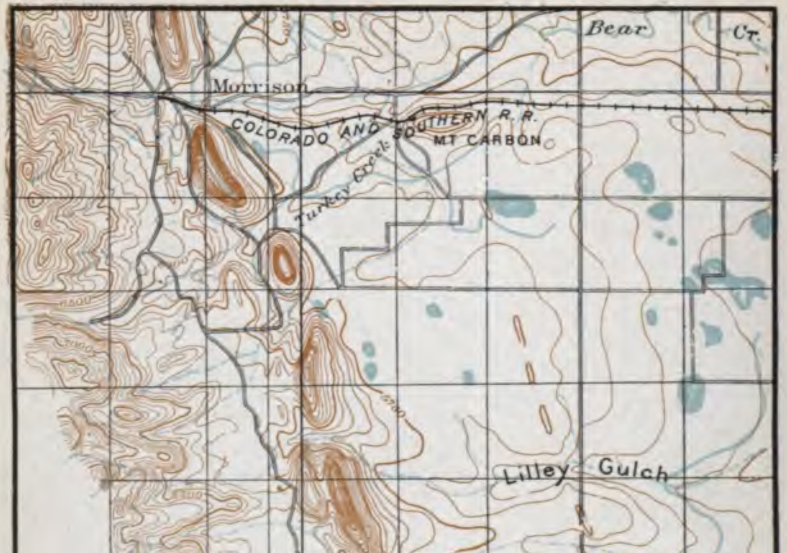
Natural bridges. If a stream with a waterfall flows over rock in which there are deep, open cracks, as is sometimes the case, a *natural bridge* may be formed. Some of the water of such a stream may descend through a crack (as at *b*, Fig. 115). After reaching a lower level, it may find or make a passage through the rock to the river below the falls. If even a little water follows such a course, *it will make its passageway* (*b*, *c*, *d*, *e*, Fig 115) larger, and in time it

PLATE XI



The Niagara Gorge. Scale about 1 mile per inch. (Niagara Falls, N. Y., Sheet, U. S. Geol. Surv.)

PLATE XII



An area southwest of Denver, showing a mountain ridge dissected by erosion. The mountain range appears as a series of long hills in line. These long hills are the outcropping edge of a tilted layer of hard rock. The breaks in the ridge are the results of erosion. Ridges of this sort are often called *"hogbacks."* *Scale* about 2 miles per inch. (Denver, Colo., Sheet., U. S. *Geol. Surv.*)

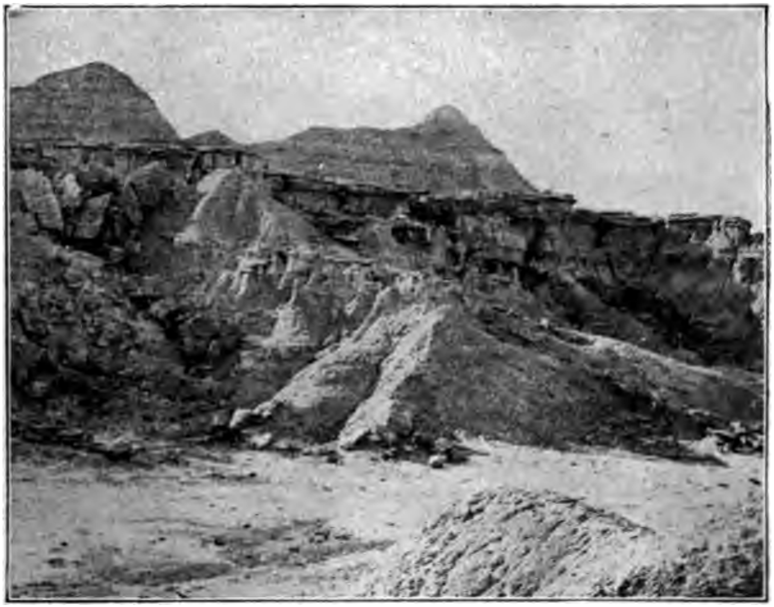


Fig. 114.—Bad lands of South Dakota. (Williston.)

may become large enough to carry all the water of the river. In this case, the entire fall will be shifted from its first position at *f* (Fig. 115) to the enlarged joint *b*. The fall will then wear back the face of the rock over which it drops, and the fall will recede upstream. The underground channel between the old fall and the

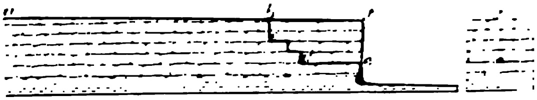


Fig. 115.—Diagram to illustrate the initial stage in the development of a natural bridge. Longitudinal section at the left, cross-section at the right.

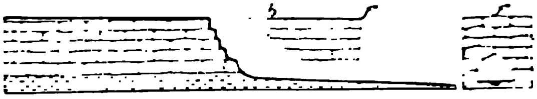


Fig. 116.—A stage later than that shown in Fig. 115

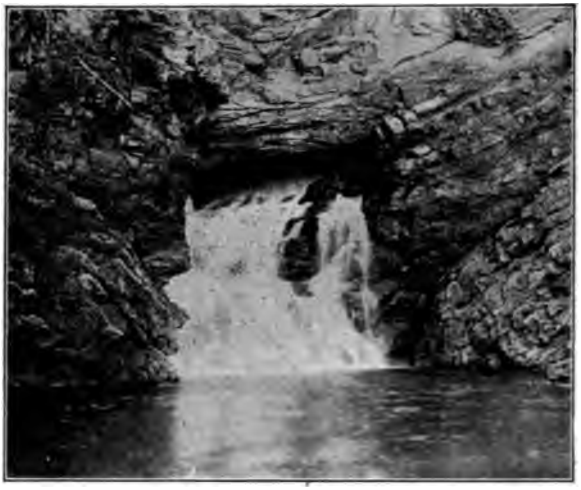


Fig. 117.—A partially developed natural bridge in Two Medicine River, Mont. (Whitney.)

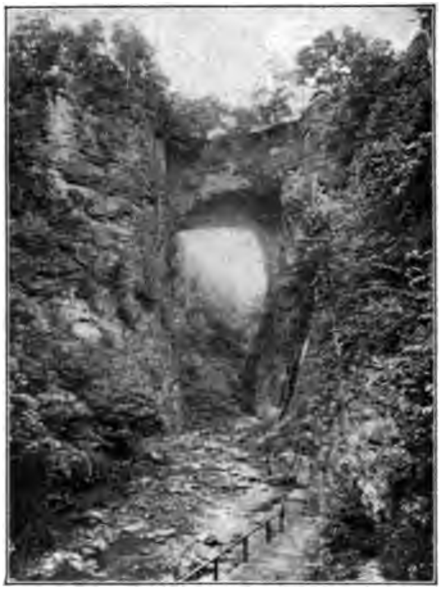


Fig. 118.—The Natural Bridge of Virginia. (U. S. Geol. Surv.)

new would be bridged by rock (bf' and f', Fig. 116). A natural bridge of this sort is now in process of development in Two Medicine River in northwestern Montana (Fig. 117). After being formed, a natural bridge will slowly weather away. The Natural Bridge near Lexington, Va. (Fig. 118), almost 200 feet above the stream which flows beneath it, was probably developed in this way. It is not to be understood, however, that all natural bridges have had this history.

Rapids and falls. The bed of a stream is often steeper at some point than at others, and there the stream flows more rapidly. In such a case as that shown in Fig. 119, the quickened flow constitutes a *rapids*. If the water in a stream's bed drops over a cliff, it makes a *waterfall* (Fig. 120), and between waterfalls and rapids there are all gradations (Fig. 121). Steep rapids are often called falls, and both are sometimes called *cascades*.

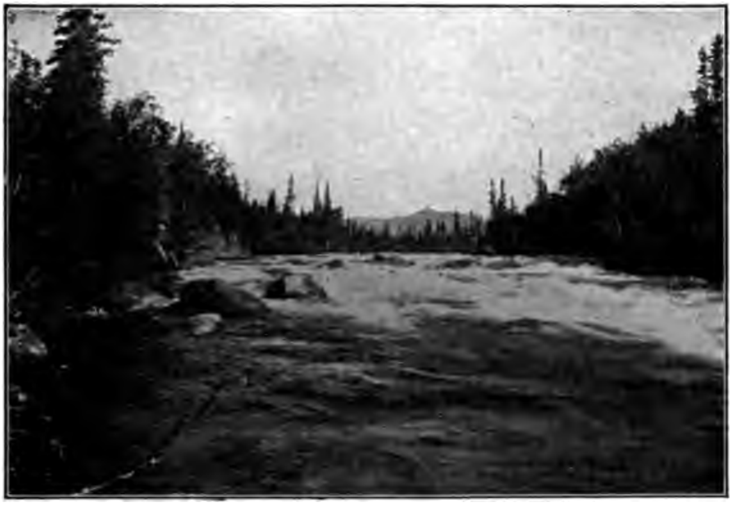


Fig. 119.—Rapids; outlet of Walker Lake, Alaska. (U. S. Geol. Surv.)

The falls and the rapids of many rivers add greatly to their beauty, and sometimes enhance their value to mankind by affording abundant water-power. Niagara Falls affords about 4,000,000 horse-

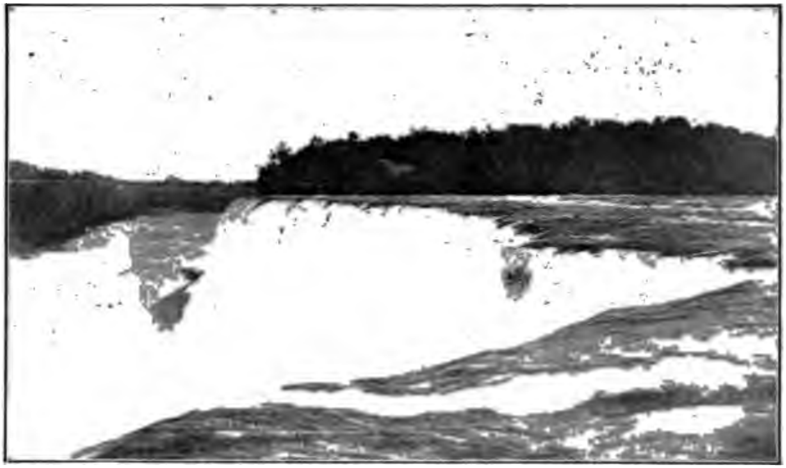


Fig. 120.—Niagara Falls. (U. S. Geol. Surv.)

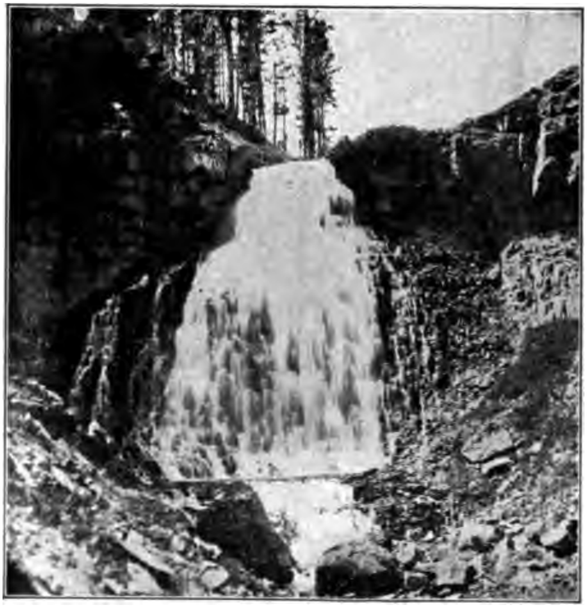


Fig. 121.—Rustic Falls. A succession of slight falls in the Yellowstone Park. (U. S. Geol. Surv.)

power, so much of which has been or seems likely to be granted to manufacturing companies, that a movement has been begun to "save the Falls." The Falls of St. Anthony did much to make Minneapolis the greatest flour manufacturing city of the world. Some of the great manufacturing cities of New England also grew up about low falls and rapids. Advantageous as rapids and falls are as a source of power, they are enemies of navigation. In the early days, the rapids of the Ohio at Louisville prevented the passage of steamers, and so determined the location and early growth of that city. A canal around the rapids was completed in 1830.

Waterfalls come into existence in various ways. If the rock in the bed of a stream is of unequal hardness, the less resistant part will be worn more rapidly than the more resistant part farther upstream, with the result shown in Fig. 122. The continued wear of the water in such a case would cause the rapids at *c* (Fig. 122) to become steeper, and in time the descending water would become a fall (Fig. 123). In this case, *the rapids and falls depend on inequalities of hardness in the bed of the stream.* This is, perhaps, the commonest way in which falls and rapids originate. Fig. 124 shows the structure of the rock at Niagara, where the fall is due to a harder layer of rock above others which are not so hard. A landslide or a

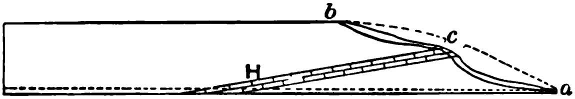


Fig. 122.—Diagram representing an early stage in the history of a waterfall. The diagram represents a vertical section through the rock. *H* is a hard layer, and *b a* represents the slope over which the water began to run. In time, the gully develops the profile *b c a*, and the water flows more swiftly just below the hard layer, making a rapids. A little later, the profile of the valley becomes *c c'*, Fig. 123, and the rapids become more rapid.

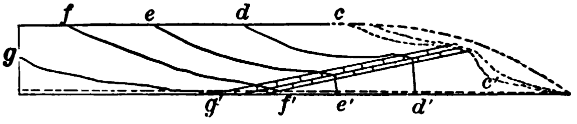


Fig. 123.—This figure shows a further development of the process illustrated in Fig. 122. The profile of the stream becomes *d d'*, when there is a pronounced fall; *e e'*, when the fall becomes lower; *f f'*, when the falls have again become rapids; and *g g'*, when the rapids have disappeared.

lava flow may form a dam, over which the water falls or flows in rapids. These are some of the ways in which rapids and falls arise.

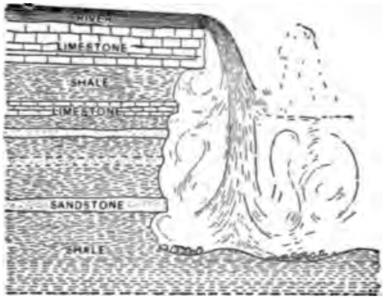


Fig. 124.—Diagram illustrating the conditions at Niagara. (Gilbert.)

At the bottoms of falls, ***pot-holes*** (Fig. 125) are sometimes developed. They are started in the softer spots in the rock. They are worn larger by the eddying of the water in the holes, and especially by the stones which the eddies whirl about.

Falls and rapids are undergoing constant change, although the change is usually very slow. The falls of the Niagara are moving slowly up-stream, because the falling water undermines the hard layer of rock over which it drops

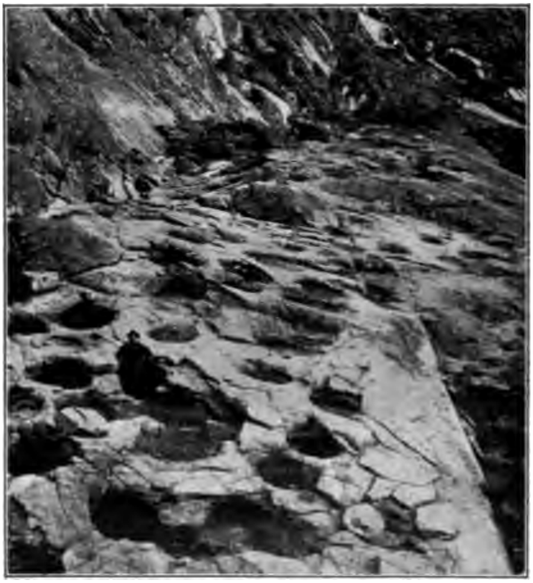


Fig. 125.—Pot-holes in granite. Upper Tuolumne River, Cal.

(Fig. 124). As a fall recedes, it generally becomes lower (Fig. 123). In such cases, it is clear that the fall will disappear if it recedes far enough. If the hard rock over which the water drops is in the position shown in Fig. 126, the fall will not recede, though it will become lower, and will disappear when the stream cuts down to base-level where the fall is. Rapids and falls are therefore temporary features of streams. Like canyons, they are marks of youth. In time, all rapids and waterfalls will disappear, for they cannot exist after rivers have reached base-level, the goal of every stream.

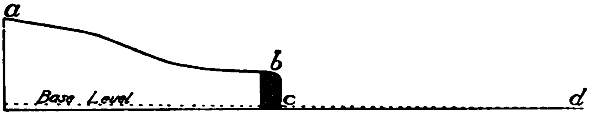


Fig. 126.—Diagram illustrating a condition where a fall will not recede.

Narrows. A valley often becomes narrow where it crosses a layer of hard rock. Such a constriction of the valley is a *narrows*, or a *water gap* (Fig. 127). The Delaware Water Gap (Fig. 128) through the Kittatinny Mountain (Pa., N. J.) is a well-known example. Unlike falls, narrows are not most conspicuous in the youth of the stream, but at a later time, after the valley has been much

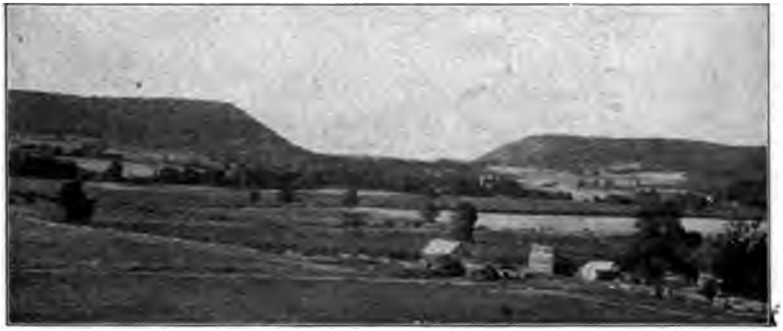


Fig. 127.—The Lower Narrows of the Baraboo River, Wisconsin. The valley widens out beyond the gap, the same as in the foreground.

widened except where it crosses the hard rock. Falls are common in horizontal or nearly horizontal beds, but narrows are developed only in tilted beds.

Narrows sometimes serve as gateways through mountains, and so control lines of travel. The narrows of the Potomac River in Wills Mountain, Maryland, may serve as an example. In the early days of American history, Fort Cumberland was built at the narrows to guard the important pass through the mountains, and Washington's and Braddock's Roads ran west through it. At the present time, the Cumberland National Road and an important railway make use of it.

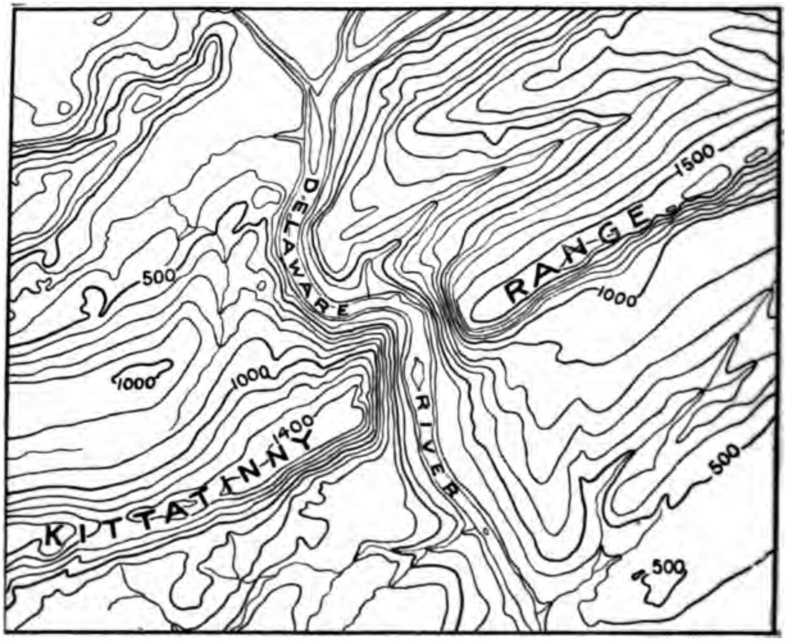


Fig. 128.—Topographic map of Delaware Water Gap. Scale about 1¼ miles to the inch. (From Delaware Water Gap, Pa.-N. J. Sheet, U. S. Geol. Surv.)

Rock terraces. Again, if the hard layer through which a stream *cuts is horizontal,* it weathers away less rapidly than the weaker

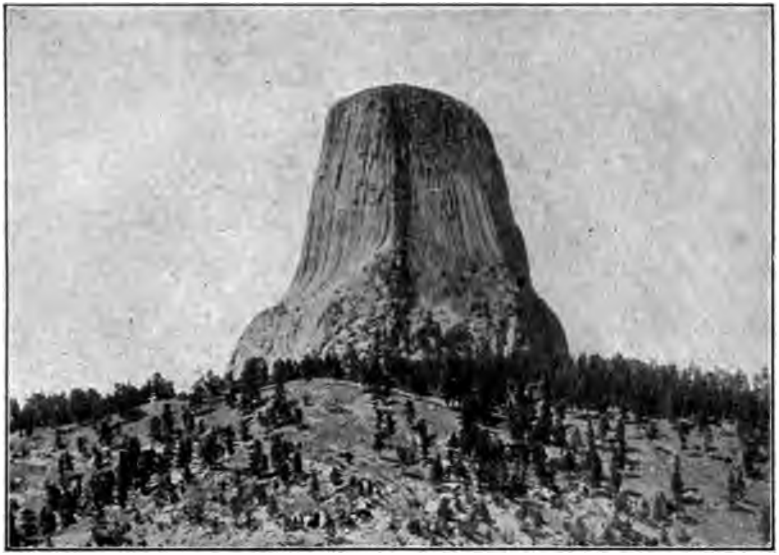


Fig. 129.—A monadnock. A mass of igneous rock isolated by erosion, and remaining because of its superior hardness. Matteo Tepee, Wyo. (Detroit Photo. Company.)

rock above and below, and so gives rise to rock terraces, as shown in Fig. 112.

Monadnocks, rock ridges, etc. Elsewhere than in valleys, too, hard rock affects the topography, for rain-wash, wind, and most

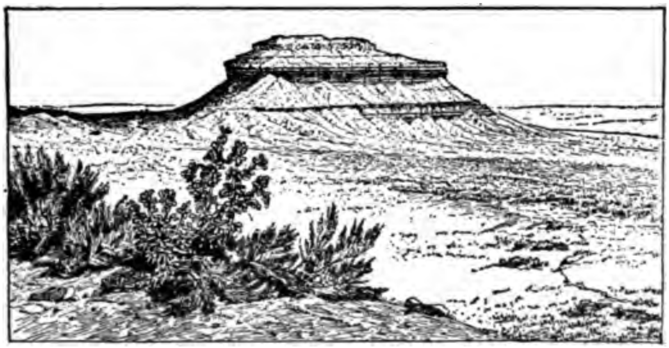


Fig. 130.—A butte. A characteristic feature of the arid plateau region of the West. The butte is really a monadnock. (U. S. Geol. Surv.)

phases of weathering wear it away less rapidly than they wear softer rock. The result is that hard rock often remains as hills, or

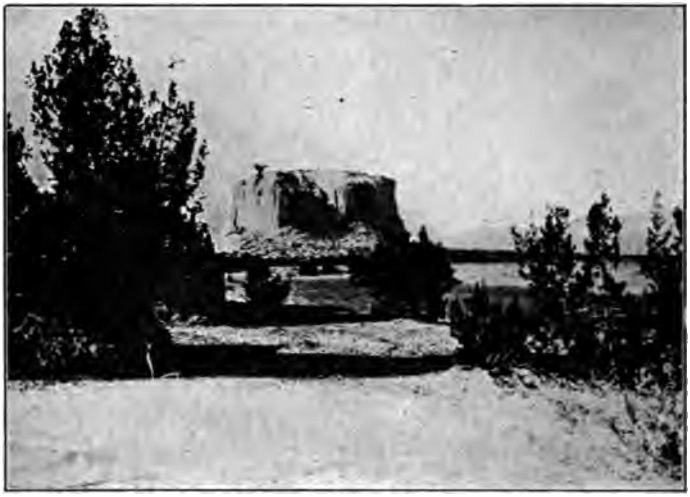


Fig. 131.—The Enchanted Mesa. A striking butte in New Mexico. The name mesa is not commonly applied to elevations of such small summit area. (Chamberlin.)

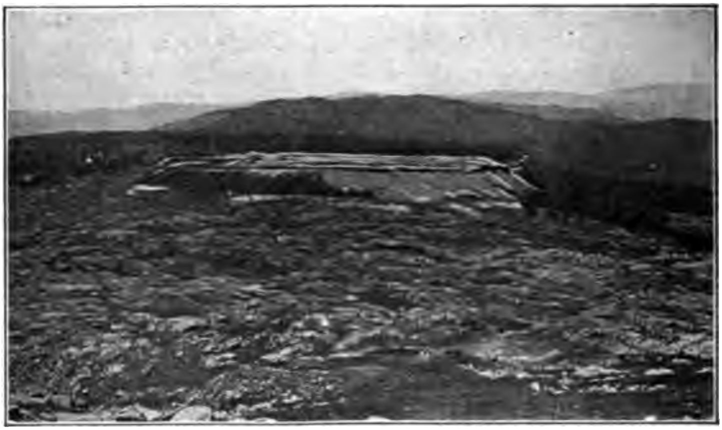


Fig. 132.—Lime Mesa, southwestern Colorado. The mesa is the flat-topped area near the middle of the picture. Mountains rise up behind it. (U. S. *Geol. Surv.*)

even as mountains (called *monadnocks*), when the weaker rock about it has been removed by erosion. Fig. 129 is an example. In the West, similar elevations are often called *buttes* (Figs. 130 and 131). If such an elevation has some expanse of surface at its top, it is a *mesa* (Fig. 132). This term is also applied to wide terraces, especially if high.

If the hard rock which gives rise to an elevation is a tilted bed of rock, the resulting elevation is long and narrow, and is often called a *hogback* (Fig. 133 and Pl. XII).

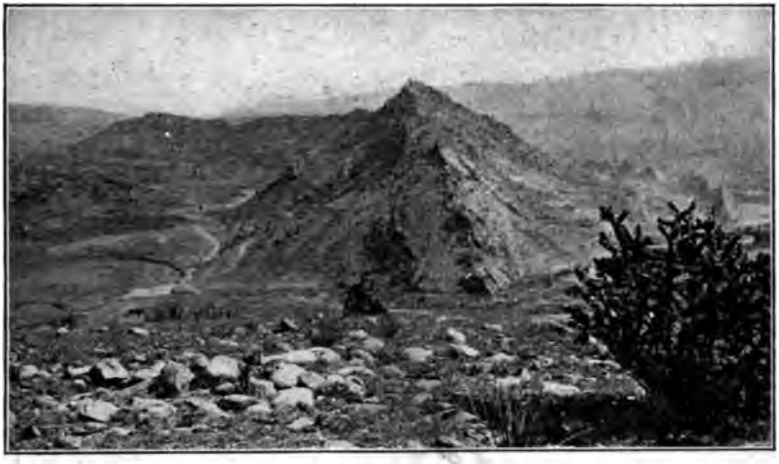


Fig. 133.—A hogback; Colorado City, Colo. (U. S. Geol. Surv.)

Accidents to Streams

Drowning. Streams are subject to many accidents. If the land through which they flow sinks, as it sometimes does, they flow less rapidly, or may even cease to flow altogether. If the lower end of a valley sinks below sea-level, the sea-water enters and forms a bay. In such cases, the lower end of the river and its valley are *drowned*. If the streams along a coast end in bays, we infer that the coast has sunk, and that its rivers and valleys have been drowned. The Atlantic coast between New York and the Carolinas is a good example (Fig. 134). Delaware Bay, Chesapeake Bay, and numerous other smaller bays are drowned rivers. Without the

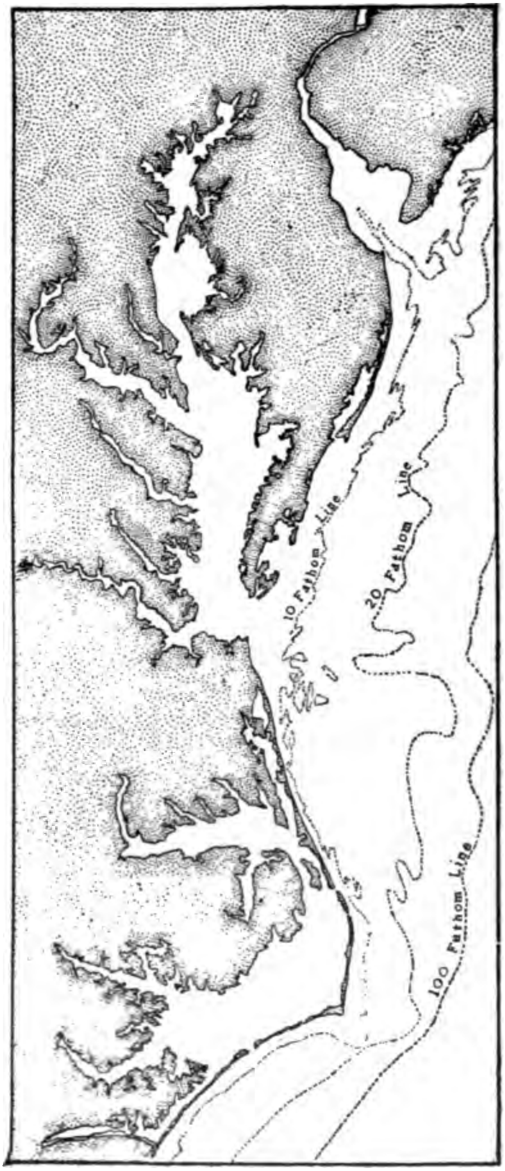


Fig. 134.—A sketch of the Atlantic coast from Cape May to Cape Hatteras and beyond, showing many drowned valleys.

drowning, the drainage of the region about Chesapeake Bay would be somewhat as shown in Fig. 136. By comparing Fig. 136 with 135, it is seen that drowning separates the parts of a river system.

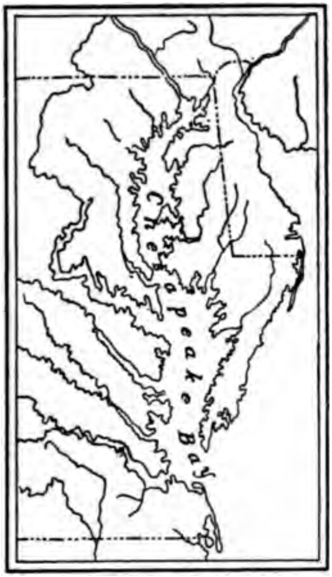


Fig. 135.

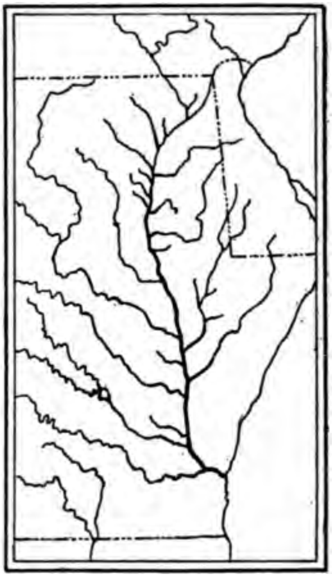


Fig. 136.

Fig. 135.—Chesapeake Bay and its surroundings. The bay is a drowned river valley, and the lower ends of its tributary valleys are also drowned.

Fig. 136.—The drainage of the region about Chesapeake Bay, somewhat as it would have been but for drowning.

Rejuvenation. If the basin of an old stream is raised so that the gradient of the stream is increased, its velocity is increased, and it again takes on the character of youth. Such a stream is said to be *rejuvenated.*

Ponding. If a part of the stream's bed is warped upward, the flow above the up-warp is checked, and the stream widened. Streams above such an obstruction are *ponded;* that is, the waters accumulate in a pond or lake. If the up-warp is great enough, it may completely dam the stream. Streams are also sometimes ponded by lava-flows, by landslides, etc., and by dams made by man. The mill-ponds along numerous creeks are illustrations of streams ponded in the last of these ways. If the ponded waters flow out over the dam made by a landslide or a lava-flow, they will ultimately cut it down. If the dam be sufficiently high, the water may leave its old course altogether and find a new route.

Piracy. One stream may steal another. One way in which this is done has been suggested (p. 96). The stream which steals is a *pirate*. The stream stolen is *diverted*, and the stream which has lost its upper waters is *beheaded*.

Piracy has been much more common among rivers than is generally known. In the Appalachian region, for example, where the conditions for piracy have been favorable, there are few large streams which have not either increased their waters by piracy, or suffered loss by the piracy of others. Figs. 137 and 138 afford one illustration. Piracy is favored by inequalities of hardness, for the streams which do not cross hard rock deepen their channels more readily than those which do.

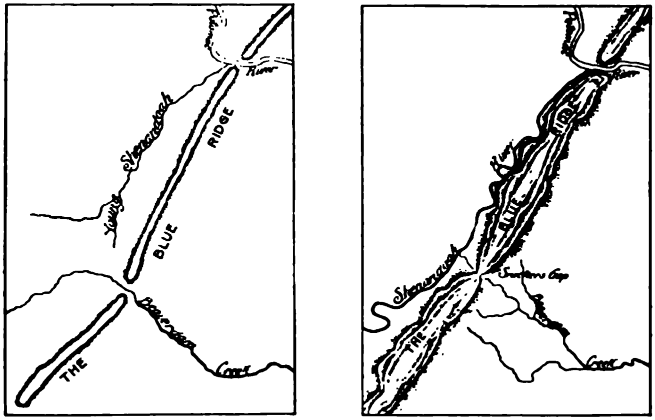


Fig. 137. Fig. 138.

Figs. 137 and 138.—The capture of the head of Beaverdam Creek by the Shenandoah River. Virginia-West Virginia. (After Willis.)

When a stream is diverted from a narrows, the water-gap becomes a *wind-gap*. Such gaps are common in most mountain regions which have advanced to late maturity. Snickers Gap (Fig. 138)

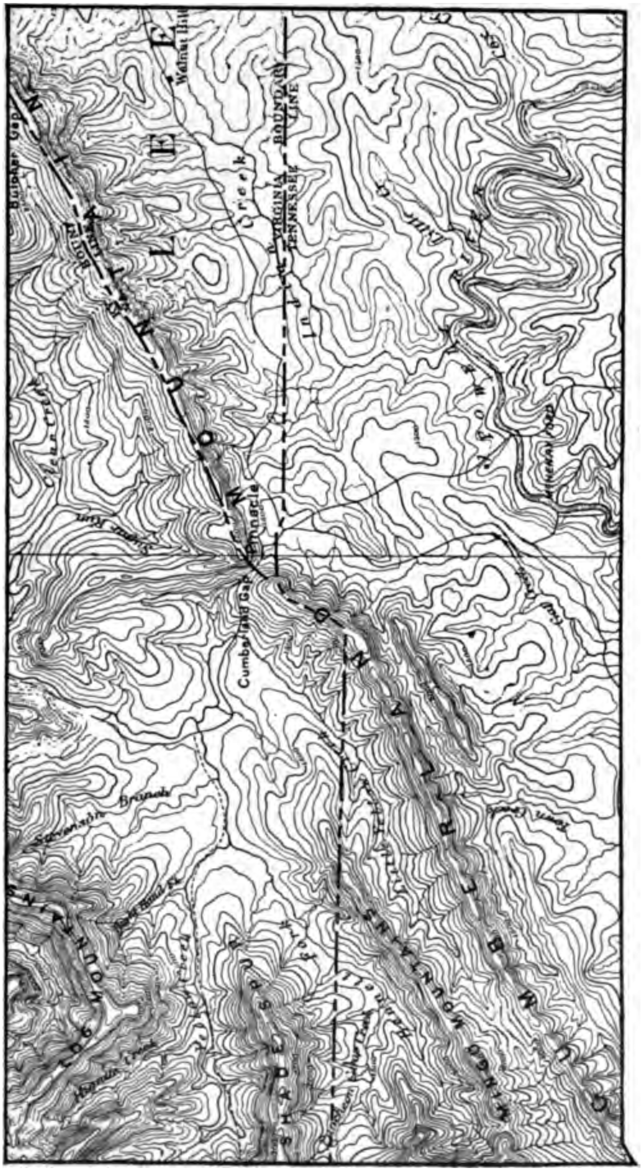


Fig. 139.—A topographic map of Cumberland Gap and its surroundings. Scale about 3 miles to the inch. (Cumberland Gap, Md.-Va.-Tenn. Sheet, U. S. Geol. Surv.)

is one example, and the Cumberland Gap (Fig. 139), in the southwestern corner of Virginia, is another. Cumberland Gap afforded the early emigrant the most available route across the mountains, and during the last quarter of the eighteenth century, probably more than 300,000 people passed through it to settle in Kentucky and Tennessee. The numerous wind-gaps of the Blue Ridge Mountains figured prominently in the westward movement of people in the early history of our continent, and again in the Civil War.

DEPOSITION BY RUNNING WATER

We have seen that rivers are always carrying mud, sand, gravel, etc., from land to sea. We have also seen that these materials are often dropped for a time on their way to the sea, to be picked up and carried on again when the conditions for transportation are more favorable. We have now to learn (1) the reasons why running water abandons some of its load, temporarily at least, (2) the places where the material is deposited, and (3) the effects of its deposition.

Causes of Deposition

When running water abandons some part of its load, it is generally because its current has been checked.

1. The commonest cause of loss of velocity is decrease of slope or gradient. This change may take place suddenly, as when running water passes from a steep slope, whether of hill or mountain, to a flat, or when it enters a lake or the sea; or it may take place slowly, as in descending a valley whose slope becomes gradually less.

2. Another but less common cause of loss of velocity is decrease of volume. Streams generally increase in size as they flow on, but to this rule there are some exceptions. (1) If, for example, a stream flows through a very dry region, it may receive little water from tributaries and springs. Evaporation, on the other hand, is great, and some of the water may be absorbed by the thirsty soil and rock through which it flows. This is especially the case if the ground-water surface (p. 47) of the region is below the level of *the stream. In a dry region, therefore, a stream may diminish as*

it flows, and may even disappear altogether (Pl. IV). (2) A stream sometimes breaks up into several streams (Fig. 140). The volume of each is less than that of the original stream, and decrease of volume means decrease of velocity. (3) Still again, many streams, especially in semi-arid regions, have much of their water withdrawn for purposes of irrigation. Many streams in the West are made smaller in this way.

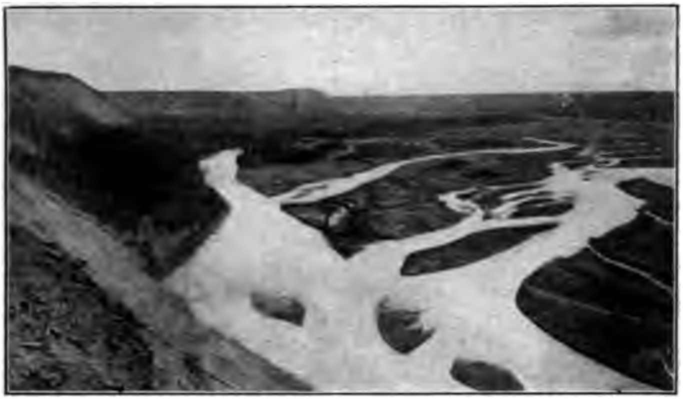


Fig. 140.—A branching stream. Junction of the Cooper and Yukon rivers, Alaska; shows bars also. (U. S. Geol. Surv.)

3. A stream may make deposits because it gets more load than it can carry, even though it does not become slower. Tributary streams with high gradients may bring to the streams into which they flow more sediment than the latter can carry away. This sometimes causes deposition in the channel of the main stream where mountain torrents with high gradients join older streams with lower gradients. Rivers may get too much load in other ways also.

Alluvial Deposits: Their Positions and their Forms

The sediments left by running water on the land are alluvial deposits. Alluvial deposits are found chiefly where the flow of the water is checked. Such situations fall into several classes.

1. At the bases of steep slopes. Every shower washes fine sediment down the slopes of hills and mountains, and much of it is left at their bases. In such situations, fences are often buried, little by little, by the mud lodged against them. The temporary streams which follow showers sometimes flow down steep slopes, and are suddenly checked at their bases. Such streams gather much debris in their headlong courses down the slopes, but abandon it where their velocity is suddenly checked. Thus at the lower end of every new-made gully on the hillside, there is a mass of debris which was washed out of the gully itself (Figs. 91 and 141). Material in such positions accumulates in the form of an *alluvial cone*.

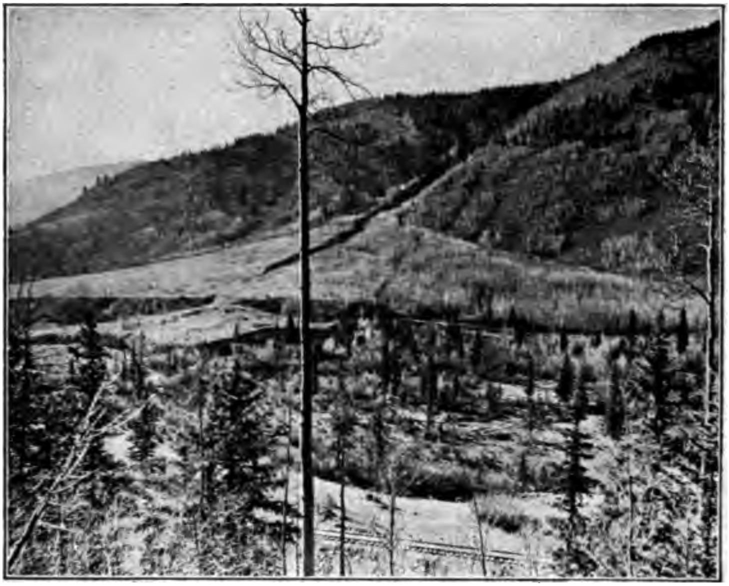


Fig. 141.—An alluvial cone or torrential fan at the mouth of Aztec Gulch, Dolores River, southwestern Colorado. (U. S. Geol. Surv.)

Conspicuous alluvial cones are common at the bases of steep slopes in semi-arid regions, for in such regions the rainfall is fitful, and the occasional heavy showers which give rise to temporary torrents favor the development of cones of great size. At the bases of the mountain ranges in the Great Basin the talus and alluvial cones and fans are, in some cases, as much as 2,000 or 3,000 feet high at a maximum.

An *alluvial fan* is the same as an alluvial cone, except that it is spread out more, and has a lesser slope. The term *fan* is more appropriate than *cone* for most alluvial accumulations at the bases of steep slopes.

Nearly all young rivers descending from mountains build fans where they leave the mountains. Thus the rivers descending from the Sierras to the great valley of California build great fans at the foot of the range, and most of the rivers coming out of the Rockies to the plains east of them do the same thing. The fans of streams descending from the mountains are often many miles across. The fan of the Merced River in California, for example, has a radius of about 40 miles.

The fans made by neighboring streams often grow until they unite. The union of such fans makes a *compound alluvial fan,* or a *piedmont alluvial plain* (Pls. IV and XIII). Such plains exist at the bases of most considerable mountain ranges. The depth of alluvial material in such situations is often scores and sometimes hundreds of feet. Fans and piedmont alluvial plains are developed especially in the youthful stages of erosion. After the valleys have been well established, the streams that flow through them are better able to carry away the debris which they get in the mountains.

The loose debris of alluvial cones and fans may absorb much water, and the water even of a good-sized stream sometimes sinks into its fan (Pls. IV and XIII). Before it disappears, the stream often breaks up into several smaller ones. This is because the sediment deposited by the stream in its channel fills it up so much that it cannot hold all the water. Some of it therefore runs over (out of the channel) and finds a new course. Streams which flow off from the main stream are *distributaries.*

Aside from well-developed fans and cones there is much sediment at the bases of slopes which are not steep. Such accumulations are almost as widespread as the bases of slopes themselves.

Alluvial fans and piedmont alluvial plains are often valuable for farming. In some parts of California, for example, the alluvial lands are so valuable that farms are small and highly improved.

Even in semi-arid regions they are often cultivated, the water being supplied (1) by wells, through which the debris of the fan is made to yield up the water it has absorbed, or (2) by irrigation ditches which connect with the stream farther up the valley, and lead the water out of its natural channel over the fan or plain (Pl. XIV).

2. In valley bottoms. The gradient of a stream generally becomes less as it flows on, and so it happens that sediment is distributed for great distances along valley bottoms. Some of it is left in the channels, and some of it is spread over the low lands along the streams, making them *alluvial plains.* Deposition in a valley which has no flat tends to develop one (Fig. 142).

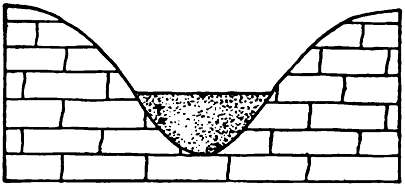
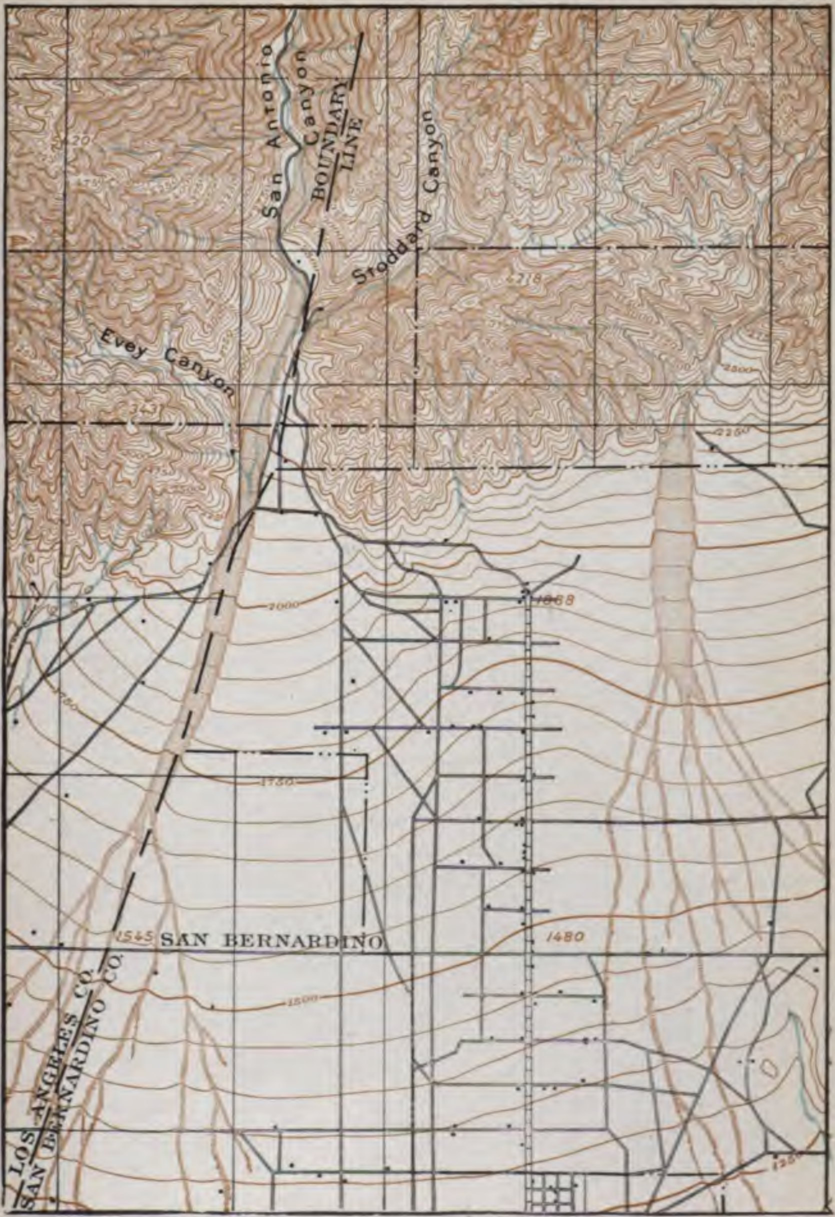


Fig. 142.— Flat developed by aggradation — diagrammatic.

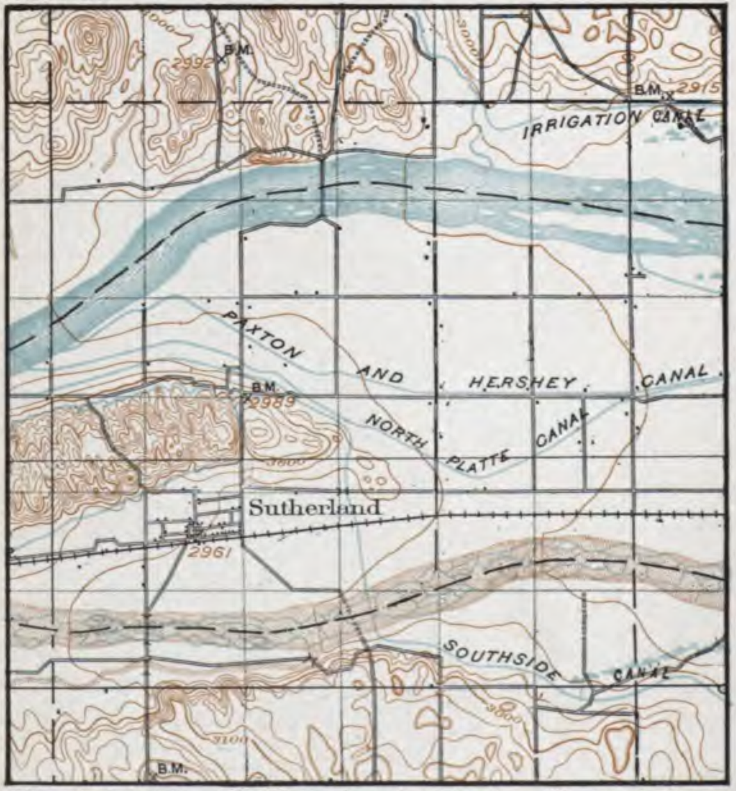
When a stream deposits sediment in its channel, the channel becomes smaller. In time it may become too small to hold all the water, and a part then breaks out, and follows a new course in the valley flat. This process may be repeated again and again (Fig. 143). The departing streams may or may not return to the main. If they do, the stream becomes a network of little streams, sometimes called a *braided stream.* The Platte River in Nebraska is an excellent example (Fig. 143). The condition shown in the figure exists only at low water. When the river is high, the whole flat through which the minor streams shown in Fig. 143 and Pl. XIV flow is covered with water, and becomes the bed of a single river.

Streams sometimes deposit sand-bars in their channels (Fig. 144), especially in low water, even when they do not become braided. Bars interfere with navigation, especially when the rivers are low. The bars are often swept away in times of flood, when the streams are swift, but they frequently form again when the flood is past. Occasionally bars become more or less enduring islands. If they



A piedmont alluvial plain or compound alluvial fan in Southern California. *Scale about 1 mile per inch.* (Cucamonga, Cal., Sheet, U. S. Geol. Surv.)

PLATE XIV



The alluvial plain of the Platte rivers in Nebraska. The South Platte is braided and the North Platte shows bars. The map also shows irrigating canals leading out from the river. Scale about 2 miles per inch. (Paxton, Neb., Sheet, U. S. Geol. Surv.)

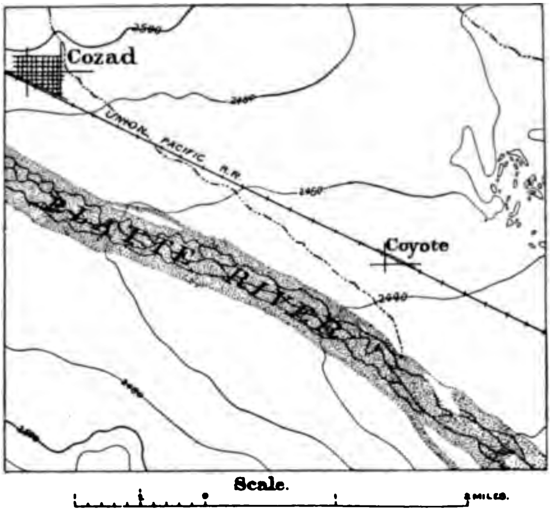


Fig. 143.—A braided river, Dawson Co., Neb. (U. S. Geol. Surv.)

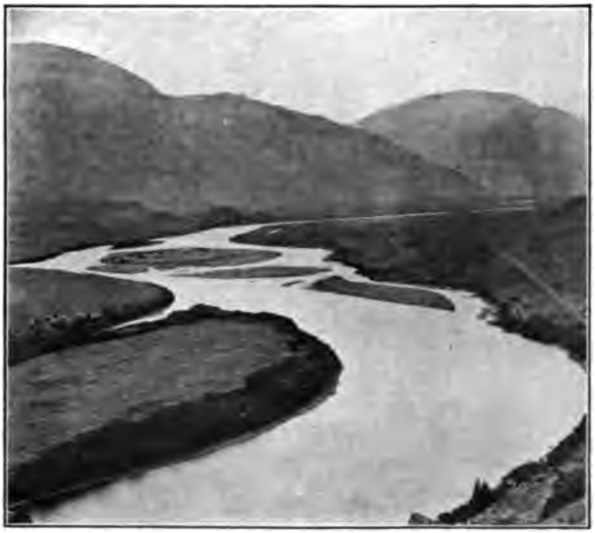


Fig. 144.—Bars in river. The Yellowstone River, 34 miles south of Livingston, Mont.

become covered with forests, they are not likely to be washed away, for the roots tend to hold the soil against the force of the current.

The alluvial plains along rivers are almost flat, though they slope gently down stream. They have a few features, however, which deserve mention, and among them are the *natural levees.* This term is applied to the low ridges on stream flats along the banks of the channel (Fig. 145). They are built in times of flood. At such times, the current in the main channel is swift; but as the water spreads beyond its channel over the adjacent flat, its velocity is checked promptly, because its depth becomes less suddenly. It must, therefore, abandon much of its load then and there. Repeated deposition in this position gives rise to the levees. They are sometimes high enough and continuous enough to turn the courses of tributary streams. This is well illustrated by the Yazoo River of Mississippi, which flows some 200 miles in the flat of the Mississippi River before being able to join it. Near Vicksburg the main river swings over to the east side of the valley, and thus receives its tributary, which the levees have shut off.

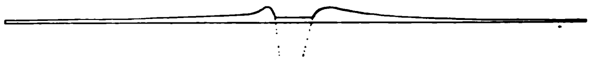


Fig. 145.—Levees of the Mississippi in cross-section, four miles north of Donaldsonville, La. Vertical scale x 50. The horizontal line represents sea-level. The bottom of the channel is far below sea-level at this point.

The early population of Louisiana and Mississippi was largely distributed in narrow belts along the levees of the Mississippi and its tributaries and distributaries. The land here was high, dry enough to be cultivated, very fertile, and close to streams, which were the great highways of that time.

Flood-plain meanders. A stream with an alluvial plain is likely to wind about (*meander*) as it flows through (Pls. VII and X). This may be said to be the result of the low velocity of such a stream, for the sluggish stream is easily turned aside. Were the course of such a stream made straight, it would become crooked again, and the manner of change is illustrated by Figs. 147 and 148. If the banks be less firm at some points than at others, as is always the case, the stream will cut more at those points. If the shape of the channel

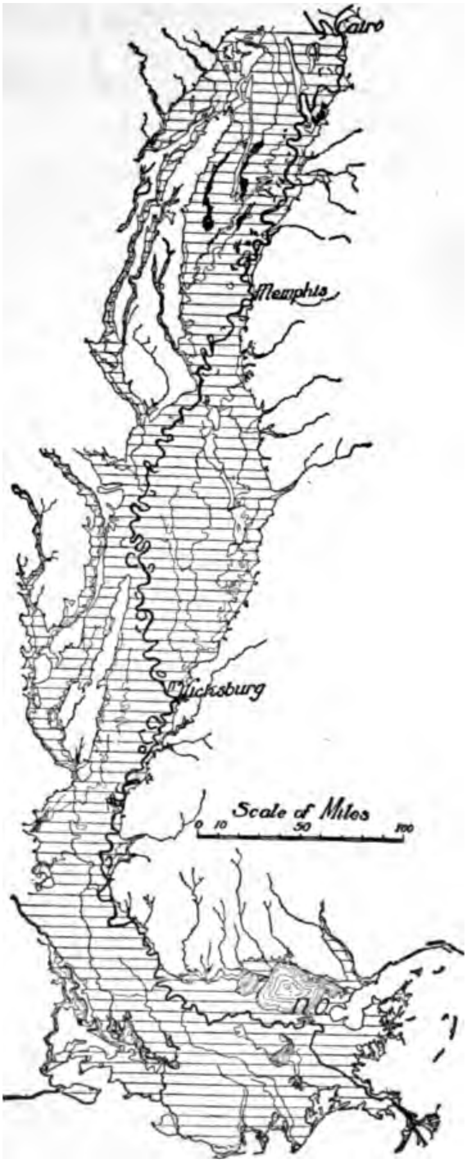


Fig. 146.—Flood plain of the Mississippi River south of the mouth of the Ohio. (From charts of the Miss. Riv. Commission.)

is such as to direct a current against a given point (*b*, Fig. 147), the result is the same, even without difference of material. If a curve in the bank is once started, it is increased by the current which is directed into it, and as the current comes out of a curve, it is directed against the opposite bank and develops a curve at that point. The water issuing from this curve tends to make another, and so on.

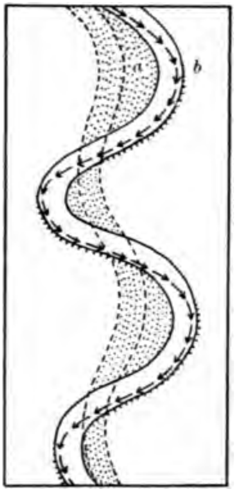


Fig. 147.

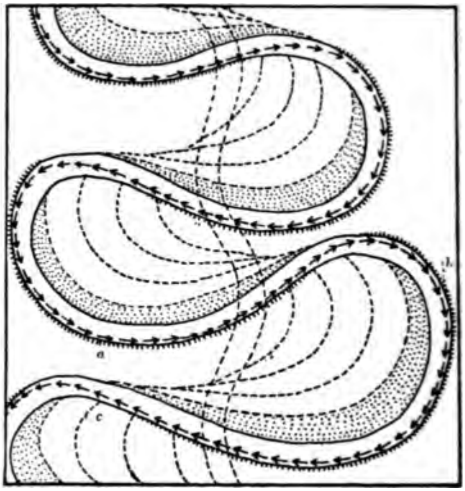


Fig. 148.

Fig. 147.—Diagram illustrating an early stage in the development of river meanders. The dotted area represents the area over which the stream has worked.

Fig. 148.—A later stage in the development of meanders.

After being started, meanders tend to become more and more pronounced (Fig. 148). In the case shown in Fig. 1, Pl. VII, the neck of land between curves has become very narrow. When it is cut through, the stream will abandon its wide curve. A later stage in the process is shown in Fig. 2, Pl. VII.

When the stream has cut off a meander, the abandoned part of the channel often remains unfilled with sediment. If it contains standing water, as it often does, it becomes the site of a lake (Fig. *149, and Pl. VI*). Such lakes are called *oxbow lakes*, or *bayous*.

In meandering, a stream sometimes reaches and undermines the valley bluff, thus widening its valley flat (Pl. V). This is, indeed, the most important process in the widening of valley flats. While river deposition sometimes makes river flats (Fig. 142), and while it always tends to widen them, because it builds up their surfaces, it should be remembered that erosion at the sides of the channel is the most important process in their development.

By the shifting of their courses, as the result of deposition and meandering, streams have affected human interests in many ways. Villages which have grown up on the banks of navigable rivers, because of the river trade, have sometimes been left far inland by changes in the positions of the streams. Such villages usually decay when the streams withdraw their patronage. Other villages built on flood plains have been washed away, while others have been preserved at great expense.

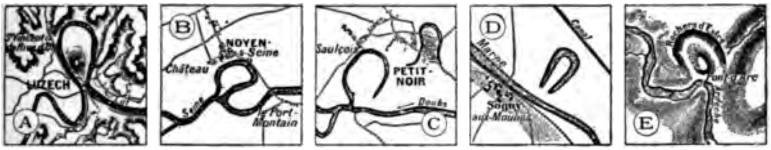


Fig. 149.—A series of diagrams showing various stages in the development of meanders. (Robin.)

Streams are often the boundaries between counties and even states. In such cases, the shifting of the stream introduces many complications into the boundary lines. The case is even more serious where a river forms an international boundary. Thus the shifting of the Rio Grande makes it an unsatisfactory boundary between the United States and Mexico.

Fertility of alluvial plains. Alluvial plains are often very fertile, and many of them are of great value for farming purposes. This was as true in ancient times as now, for the valleys of the Nile, the Po, and many of the rivers of southern Asia were the garden spots of ancient civilizations. The deposits of silt and mud made on such plains whenever the rivers flood them continually renew the soil and keep it fertile. So strictly were the earliest civilizations confined to valley plains that the period antedating 800 B. C.

has been called, with some propriety, the "fluvial period" of history. In America, valleys have been sought out for habitation from the earliest times. In Virginia and Maryland, early settlements were made in the valleys of the James and the Potomac; and in Pennsylvania, in the valleys of the Delaware, the Schuylkill, and the Susquehanna. In New York the principal settlements were long confined to the valleys of the Hudson and the Mohawk, and when the settlements in Massachusetts began to spread beyond the coast, they occupied the valley of the Connecticut.

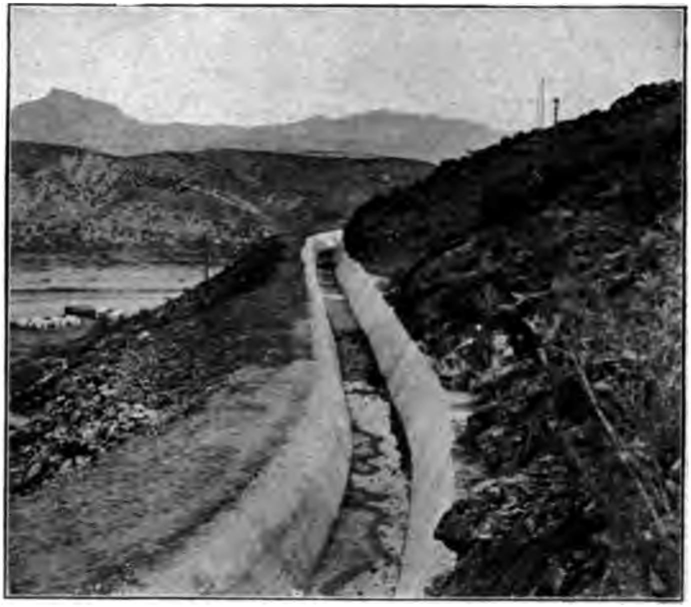


Fig. 150.—Cement-lined canal in connection with the Salt River irrigation project, Arizona. (U. S. Rec. Serv.)

Alluvial plains are well situated for irrigation. Fig. 150 shows an irrigation canal into which water will be turned at the point where the canal leads off from the stream. Fig. 151 shows a canal filled with water, along which luxuriant vegetation has sprung up. Trees along the canals serve a useful purpose, for by shading the

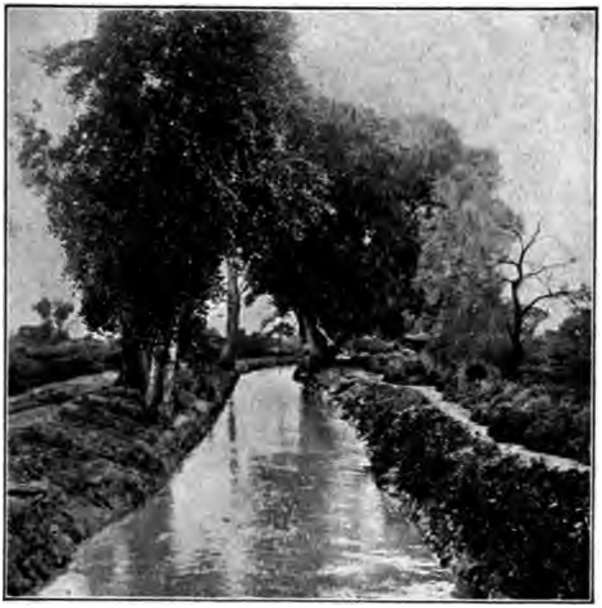


Fig. 151.—An irrigating canal filled with water. Salt River Valley, Ariz. (U. S. Geol. Surv.)

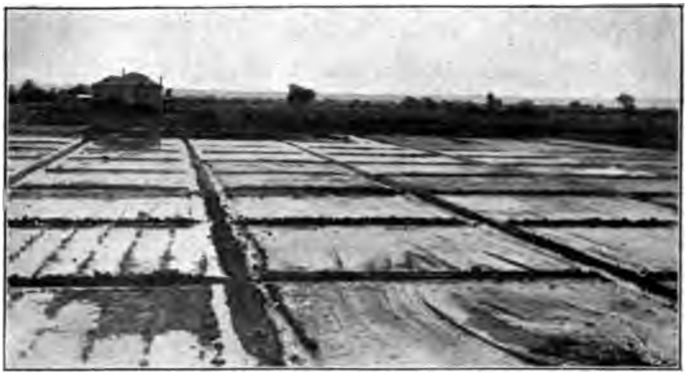


Fig. 152.—Fields prepared for irrigation by methods of squares. Las Cruces N. M. (Fairbanks.)

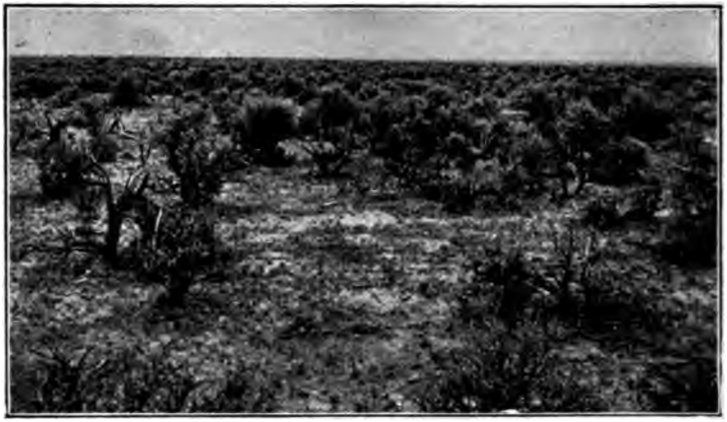


Fig. 153.—Desert land before irrigation. (U. S. Rec. Serv.)

canal they diminish the evaporation. Fig. 152 shows a field prepared for irrigation. Water is turned from the canals into the small ditches of the field, as needed.

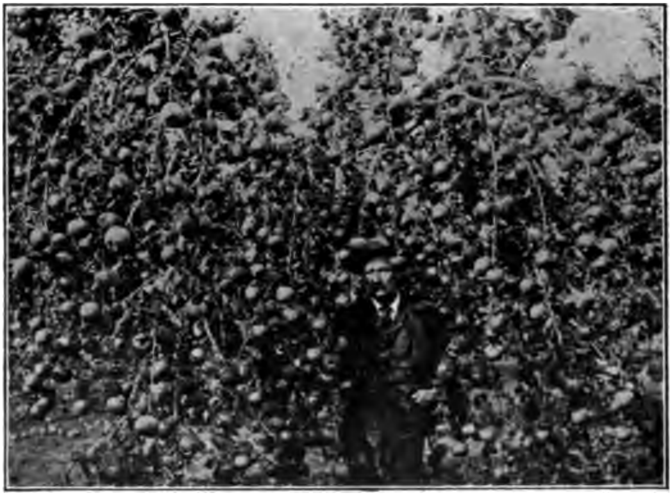


Fig. 154.—An apple-tree on irrigated land which was desert before water was applied. (U. S. Rec. Serv.)

Great progress has already been made in the use of the arid lands in the western part of the United States for farming purposes. The lands thus used are mostly in valleys and on plains adjacent to mountains. The government has undertaken the construction of many reservoirs for water in favorable places in the mountains, to hold the waters of the wet seasons, so that they may be drawn out and used on the lands below during the growing season. The sites selected for dams are usually narrow places in the mountain valleys. The distribution of the lands now irrigated, or soon to be irrigated by projects under government control, is shown in Fig. 155.

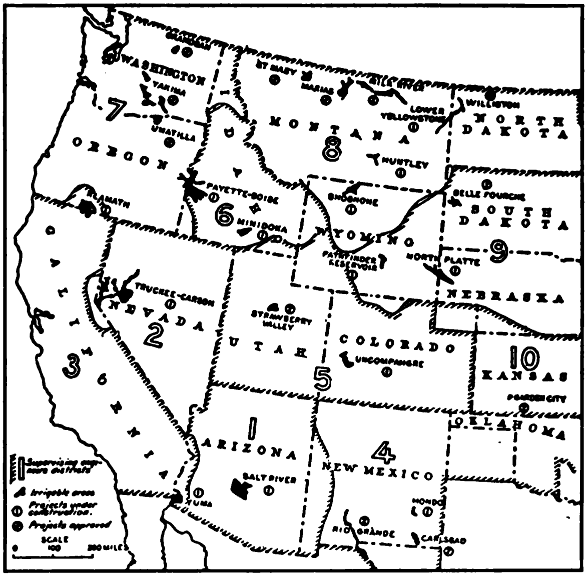


Fig. 155.—Map showing irrigation projects completed and under construction; spring, 1906. (U. S. Rec. Serv.)

River floods. Although alluvial plains are generally fertile, they are not without their drawbacks as farming regions, for the floods to which they are subject are often disastrous both to life and to property. Some parts of the rich flood plain of the Mississippi, used for farming, are so subject to floods that all buildings connected with the farms are placed above the flat.

The destruction caused by floods, is of course, not confined to farms, but extends to cities and villages as well. Terrible illustrations of the havoc wrought by floods are furnished by many rivers.

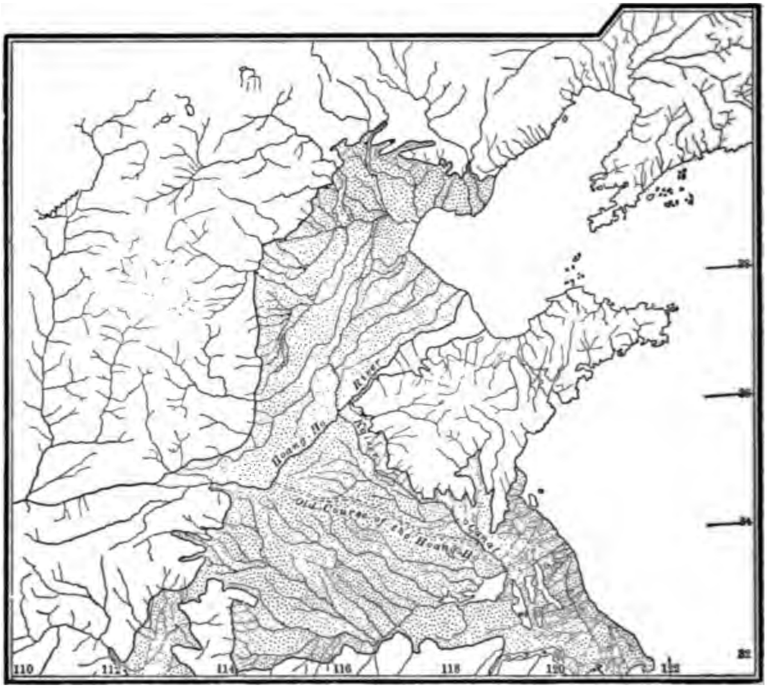


Fig. 156.—Diagram illustrating changes in the course of the Yellow River. The shaded area represents the area subject to flooding by the main stream and its tributaries. (Richthofen.)

In the spring of 1897, many thousand square miles of the flood plain of the Lower Mississippi were covered with water, and 50,000 to 60,000 people suffered serious loss. In 1881 and 1882 the floods of the same stream and of the Ohio are estimated to have caused a loss of $15,000,000 and 138 lives. The losses occasioned by the floods of the Ohio alone were estimated at $10,000,000 in 1884, and at $4,000,000 in 1903. There was a disastrous flood in the valley of the Wabash, and another in the valley of the Susquehanna, in 1904, each causing the destruction of property to the extent

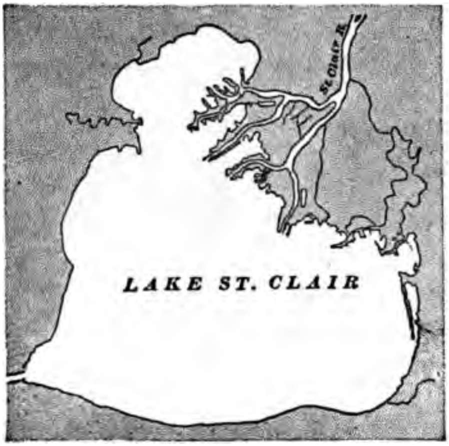


Fig. 157.—Delta of Lake St. Clair. (Lake Survey Chart.)

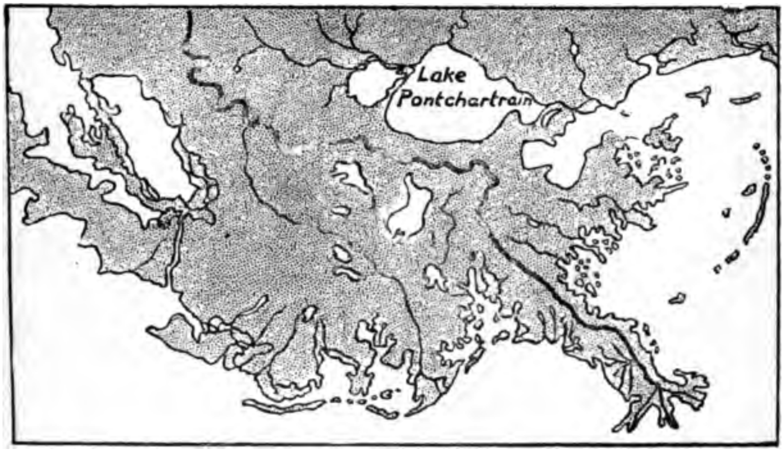


Fig. 158.—A general view of the lower part of the delta of the Mississippi.

of several million dollars. An exceptional flood of the Passaic River (N. J.), in 1902, destroyed several million dollars worth of property in 1902, and an equally destructive flood occurred at Pittsburgh in the spring of 1907.

Disastrous floods occur from time to time in most great valleys, but those of the Hoang Ho or Yellow River of China are perhaps the worst on record. Natural levees are sometimes built higher by man, and the gaps in them are filled, to protect the alluvial plains against floods. They often protect the flat outside against ordinary floods; but extraordinary floods sometimes burst through them, doing great damage.

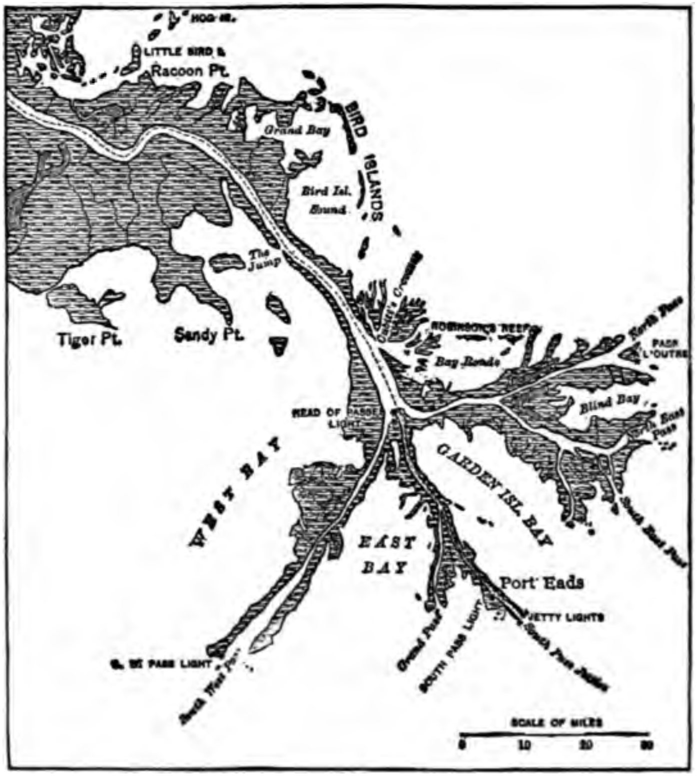


Fig. 159.—The lower end of the Mississippi, showing its distributaries. (C. & G. Surv.)

At debouchures. Where a swift stream flows into the sea, or into a lake, its current is promptly checked, and soon destroyed altogether. Its load is therefore dropped, and if not washed away by waves, etc., makes *deltas* (Figs. 157–161).

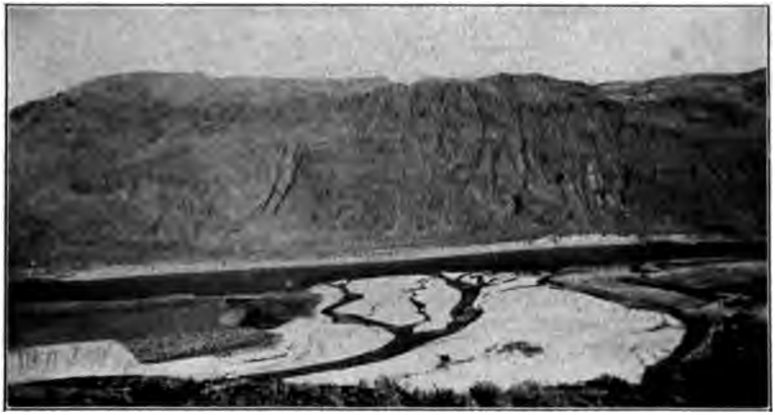


Fig. 160.—Delta of the Chelan River built into the Columbia River, Wash. (U. S. Geol. Surv.)

The delta has some points in common with an alluvial fan. In both cases, the principal deposit is made at the point where the velocity is suddenly checked. In the case of the delta, however, the current is checked more completely, and the debris is spread less widely. In form, the delta differs from the alluvial fan in that its edge has a steep slope (compare Figs. 163 and 164).

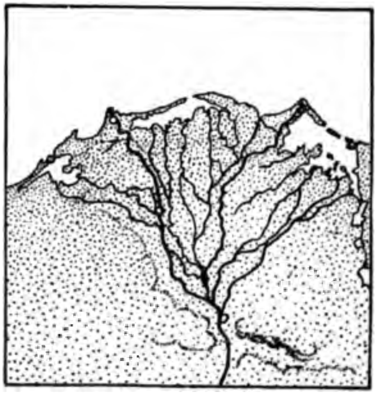


Fig. 161.—The delta of the Nile.

A delta begins below water, but it is soon built up to the water-level, and even above it. This is brought about as follows: The water flowing from the land deposits some of its sediment just beyond the shore (Fig. 165). More water descending deposits more sediment, as shown in Fig. 166. At the same time, deposition may take place just above the stream's mouth, building up the channel there a little. So the process continues until the condition shown in Fig. 167 is reached, when a considerable part of the delta is above the water. That part of the delta above the surface of the water in which it is built is like a flat alluvial fan.

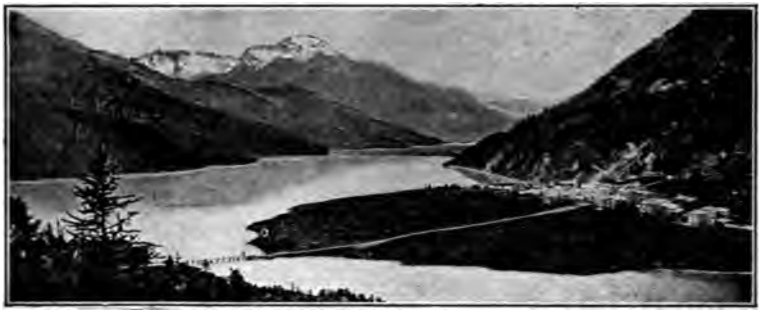


Fig. 162.— A delta in a lake. The village is Silva Plana, in the Engadine, Switzerland. (Robin.)

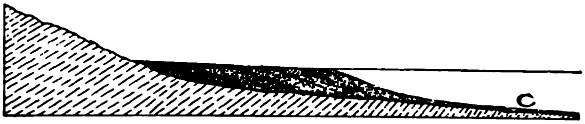


Fig. 163.—Diagrammatic profile and section of a delta.

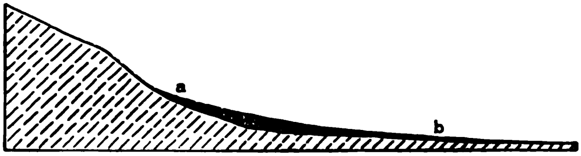


Fig. 164.—Diagrammatic profile and section of an alluvial fan.

Waves, currents, etc., may prevent the building of a delta, but *otherwise all sediment-bearing* streams make deltas where they enter seas or lakes. Deltas are sometimes built where one stream flows into another (Fig. 160), especially where a swift stream with much sediment joins a slow one. Deltas built into rivers are usually small.

Much land has been made by the growth of deltas. Thus the Colorado River has built a great delta many square miles (above water) in area at the head of the Gulf of California (Fig. 168). The delta has been built quite across the former gulf near its upper end, shutting off the head. In the arid climate of the region, this shut-off head became a nearly dry basin, the lowest part of which is about 300 feet below sea-level.

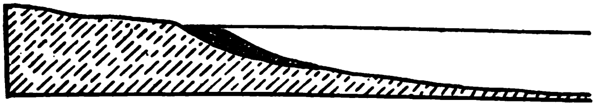


Fig. 165.—The first stage in the formation of a delta.

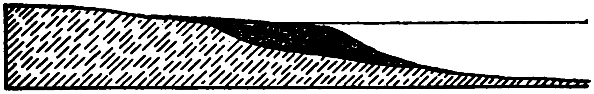


Fig. 166.—A later stage in the formation of a delta, after deposition has built up the landward part of the delta to sea-level, and a little above.

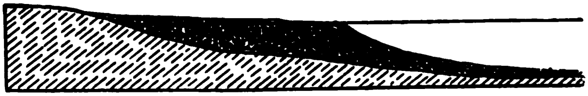


Fig. 167.—A still later stage in the development of a delta.

In 1906, this low land gave much trouble. The Colorado River broke out of its banks where it crossed the land of its own making, and took a new course into the low area to the north (Fig. 169). Pouring into this basin, it made a great lake, called the Salton Sea (Fig. 168). The lake spread over farming lands, villages, and railroads, and vast sums of money were expended in turning the water back into its old course.

The Skagit River, in Washington, has built its delta out about high islands in Puget Sound, thus joining them to the mainland.

The deltas of the Mississippi (Fig. 158), the Nile (Fig. 161), and the Hoang Ho rivers (Fig. 156) are among the large and well-known ones. The delta of the Ganges and Brahmaputra is also a great one, having an area (above water) of some 50,000 square miles. The *Po has built a delta* 14 miles beyond the former port of Adria, which

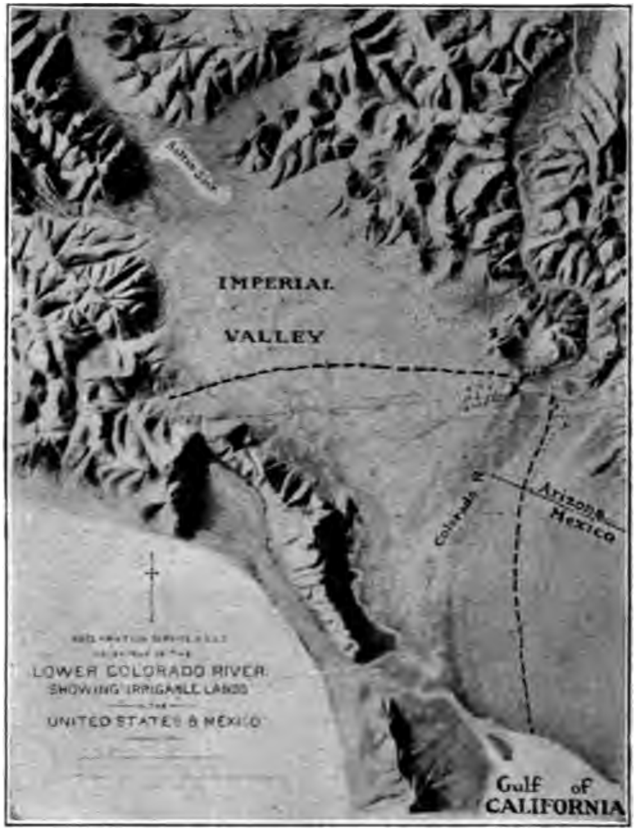


Fig. 168. -Relief-map of an area about the head of the Gulf of California, showing the delta of the Colorado River, outlined, in a general way, by dotted lines. The Salton Sink is shown at the north, and the Imperial Valley, where many farms were flooded, lies south of the sink. (U. S. Rec. Serv.)

gave its name to the Adriatic Sea. The Rhone River (France) has advanced its delta about 15 miles in as many centuries.

The outline of many deltas is determined by the surroundings in which they are built. When, for example, a delta is built in the head of a bay, the outline of the bay determines the shape of the delta. The normal form of a delta built on an open coast is roughly semicircular, though there is often a fringe of *delta fingers*, which together have some resemblance to the Greek letter delta △, which gave these terminal deposits of streams their names (Fig. 159).

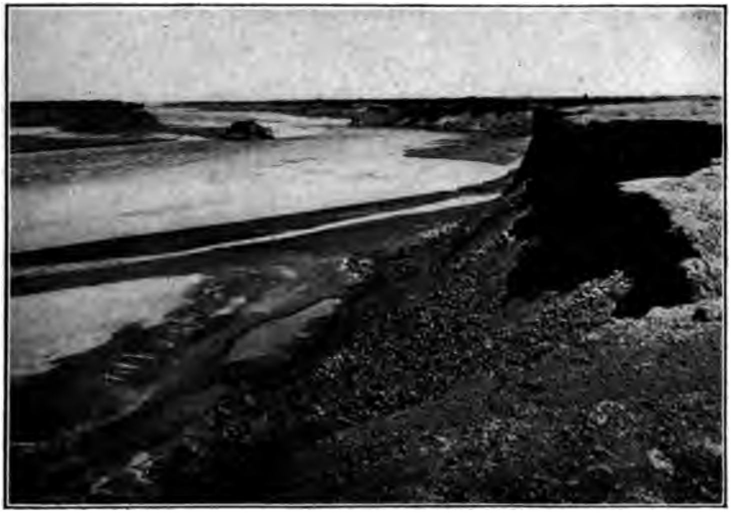


Fig. 169.—The Colorado River cutting through the Imperial Valley. (U. S. Rec. Serv.)

The surfaces of deltas are usually nearly plane (Fig. 162), and the streams which cross them often give off distributaries (Figs. 159 and 161), which are subject to constant changes. These changes sometimes affect commerce in a vital way. Thus the site of Kásimbázár, in India, described as the chief trade city of the valley of the Ganges early in the eighteenth century, is now a swamp, as a result of a sudden change in the course of the Bhagirathi River (a distributary of the Ganges) on the banks of which it stood.

Many deltas are cultivated, and some of them, like that of the Hoang Ho, support dense populations. Delta lands are, however, subject to disastrous floods. It is estimated that the flood of the Hoang Ho River in September, 1887, drowned at least a million people who lived upon its delta, and caused the death of many more by disease and famine afterward. Many villages were completely destroyed, and hundreds more were temporarily submerged. Previous to 1892, this river flowed into the Yellow Sea south of the Shan-tung promontory. In that year, it shifted its course in flood time, forming a new channel leading northwest into the Gulf of Pechili, 300 miles north of its former mouth. Comparable changes at earlier times, running as far back as 2293 B. C., are recorded in the annals of Chinese history.

Alluvial Terraces

When a river which has an alluvial flat is rejuvenated, the stream sinks its channel below the level of the flat. The remnants of the old flood plain are then *alluvial terraces* (Fig. 170). Such terraces are also formed in other ways. Thus if a stream is for a time supplied with an excess of load, it aggrades its valley (Fig. 142). If, later, the excess of sediment ceases, the stream sets to work to

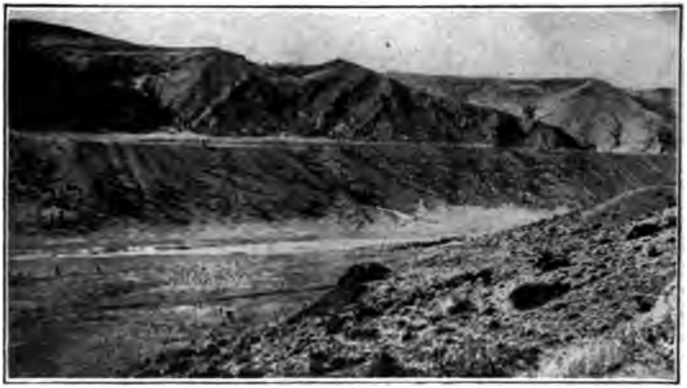


Fig. 170.—Terraces of the Columbia River, opposite Lake Chelan, Washington.

remove that which was temporarily laid aside in its flood plain. Villages and cities are often built on terraces.

River Lakes

Rivers tend to drain the lakes of high lands, but they make lakes both in their flood plains and at their debouchures. Oxbow lakes have already been mentioned (p. 132), but river lakes arise in other ways as well. A tributary stream, with a high gradient, may bring more sediment to its main than the latter can carry away. That which is deposited may form an obstruction in the channel of the main stream, ponding the water above. A river broadened in this way is often called a lake. Lake Pepin in the Mississippi River (Fig. 171) is an example.

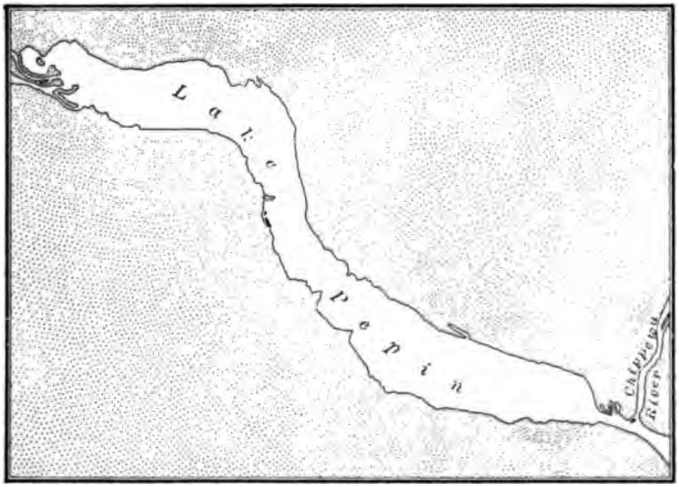


Fig. 171.—Lake Pepin, a widened part of the Mississippi River between Wisconsin and Minnesota. Maximum width about 2½ miles. The widening of the river is apparently due to the detritus brought down by the Chippewa River, and deposited in the Mississippi. (Miss. Riv. Com.)

Rafts of timber are sometimes formed in rivers, and these rafts may obstruct drainage, ponding the waters both of the main stream and of its tributaries. A huge raft of this sort developed in the Red River of Louisiana long ago. It appears to have been in reality a *tree jam.* The trees appear to have fallen into the river by the undercutting of forested banks by the meandering stream. Floating down with their branches, the trees lodged against the banks. The lodging of some trees caused others to be stopped, and so the jam, or raft, grew. By obstructing tributary valleys, the raft ponded their waters, and so gave rise to lakes (Fig. 172). The raft was cleared away in 1867, and since that time many of the former lakes have been drained and some of their former bottoms are now cultivated.

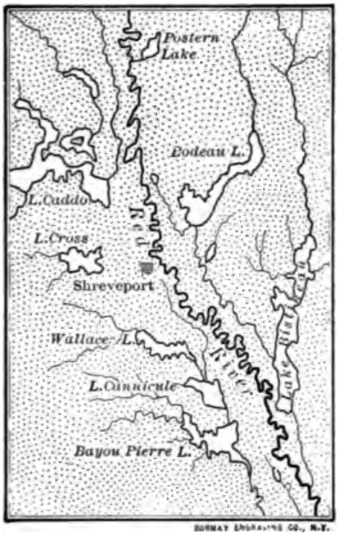


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Fig. 172.—Lakes along the Red River of Louisiana. The lakes are at the lower ends of the tributary streams.

In deltas, deposits are sometimes so distributed as to enclose bodies of water (Fig. 158) which become lakes. The alluvial cones or fans built by tributary valleys become so large, in some cases, as to obstruct a mountain valley, giving rise to a pond or lake above. The basin of Lake Tulare in California was formed in this way.

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CHAPTER V

THE WORK OF SNOW AND ICE

Snow is perhaps the most common form of ice, but ice on ponds, lakes, and rivers is familiar to all who live where the winters are cold. In middle latitudes the water in the soil and rocks freezes to the depth of several feet in winter. In some parts of the world, too, there are great glaciers of which we shall learn in the following pages. In most of its forms ice has some effect on the surface of the land.

Ice of ponds and lakes. A given weight of water occupies most space at a boiling temperature, and, like most liquids, it contracts on cooling until its temperature is brought down to 39° F.; that is, 7° above the freezing-point. If cooled below this temperature it expands slightly until it freezes.

The surface water of ponds and lakes in middle latitudes is usually much warmer than 39° in summer. At this season the water below the surface is generally cooler than that at the top, but for some distance down, and often to the bottom, it is warmer than 39°.

As the cool weather of autumn and winter comes on, the surface water cools and contracts, and, becoming heavier than the water beneath, sinks. In the small lakes of the northern part of the United States, this process goes on until all the water from top to bottom has a temperature of about 39°. In very shallow lakes and ponds this happens soon after the freezing weather of winter begins; in larger and deeper lakes it is not reached so soon; and if the lake is very deep, the water may not all be cooled to 39° during the whole winter. This is why shallow ponds and lakes freeze over soon after the ground (really the water in the soil) freezes, while deep lakes freeze over much later, or not at all. The Great Lakes do not freeze over because the surface water continues to sink all through the winter, and before the bottom waters are cooled to 39°, spring comes and cooling ceases. The Great Lakes freeze over about their borders because the water is there shallow, and is thus cooled to 39° down to the bottom.

Let us suppose that all the water of a shallow lake has been cooled to 39° F. by the beginning of winter. Since water expands slightly when cooled below this temperature, the surface water will remain at the top if it gets colder, and when its temperature falls to 32° F. it will freeze.

When water freezes it expands about one-tenth of its volume. This is why a bottle full of water breaks if the water freezes. When ice forms on a pond or lake, it expands, just as the water in the bottle does, and crowds upon the shores. The crowding of the ice may change the shore so much in a single winter that the results are readily seen, but where this is the case, much of the crowding comes from changes of temperature after the ice is formed.

Suppose a lake frozen over to the depth of a foot or two, as often happens in Wisconsin or New York. If now the temperature falls, as during a "cold snap," say to 20° below zero (-20° F.), the ice contracts, as most solids do on cooling. The ice then pulls away from the shore, or quite as often cracks open. The cracks fill with water from below, and the water freezes. After this has taken place, the ice again covers the pond or lake completely. If now the temperature rises, say to 25° F., the ice expands, and as it expands it crowds with great force upon the shores. It is sometimes shoved up on the shore many feet, or even many yards, if the shore is low and sloping (Fig. 173). If the shore is steep and not too resistant, the ice may be thrust under the soil so as to disturb it, and even so as to overturn trees upon it, as shown in Fig. 174.

Again, the water of the lake is often very shallow about its shores, and in such places it may freeze to the sand, gravel, bowlders, etc., at the bottom, and border. When the ice is shoved shoreward it carries these materials with it. Low ridges of sand or gravel, sometimes three or four feet high, are made in this way in a single winter. Bowlders pushed up by the ice year after year sometimes make "walls" around lakes; hence the name *wall lake*, which is not uncommon in the northern states (Fig. 175).

Ice in rivers. Rivers also freeze over in cold climates, and when the ice breaks up in the spring, stones and bowlders to which it was frozen in the banks, are sometimes floated miles down the river.

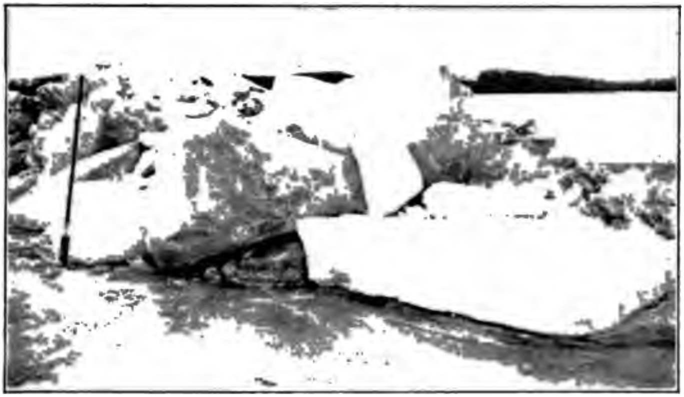


Fig. 173.—Lake ice crowded up on the shore of Lake Mendota, Wisconsin. (Buckley, Wis. Geol. Surv.)

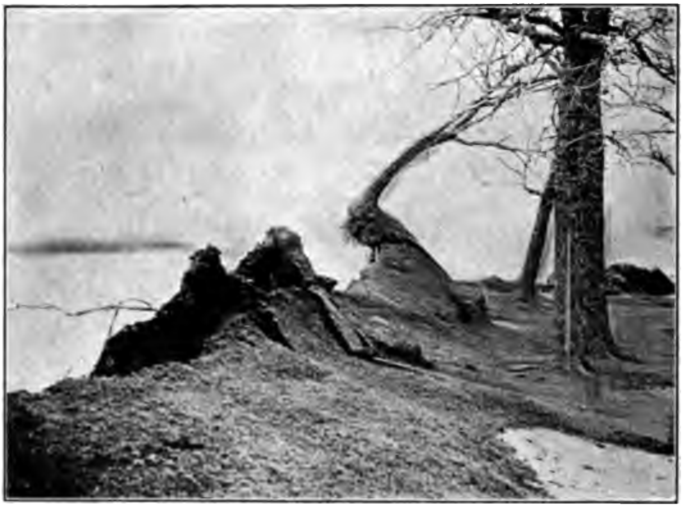


Fig. 174.—Effect of the shove of ice on the shore of Lake Mendota, Wis. (Photo. by Buckley.)

Huge pieces of rock, too, are occasionally torn from points which project into the river. At Montreal stone buildings 30 to 50 feet square, jutting out into the water so that river ice forms about them, have been moved by the ice of the St. Lawrence.

When the river ice breaks up in the spring, masses of it may be floated down-stream, and may gather in vast fields or "jams" behind dams or bridges, and the dams or bridges may be swept away. The jams themselves form a sort of obstruction, holding back the water and causing floods above. When the jams break, the waters above may sweep down the valleys with destructive violence.

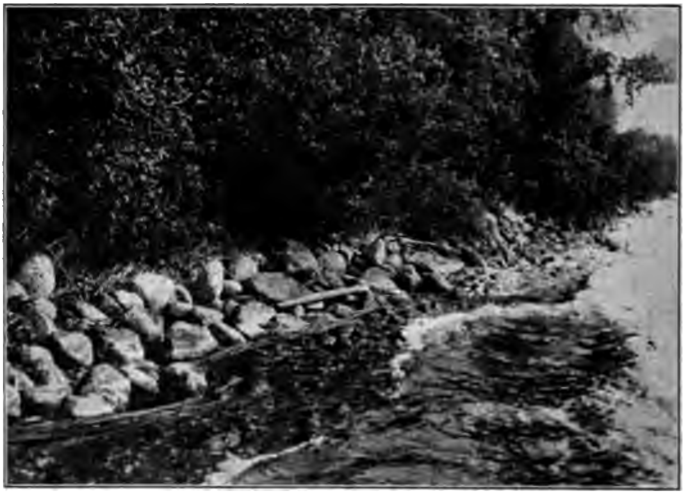


Fig. 175.—Shore of Wall Lake, Iowa. (Photo. by Calvin.)

When frozen over, the rivers of northern latitudes sometimes serve as roadways. During cold winters teams are driven across the upper part of the Mississippi, sometimes for two or three months, making long circuits to bridges or ferries unnecessary.

Ice on the sea. Sea-water does not freeze so readily as fresh water, for its freezing temperature is 26° to 28° F., instead of 32°. The exact temperature of freezing depends upon the amount of salt it contains, and this varies a little from place to place. Unlike fresh water, salt water condenses until it freezes. In high latitudes ice forms on shallow sea-water, and in polar regions it becomes several feet deep, not only along shores but on the open sea.

The sea-ice is often broken up in the summer, and the floating pieces are called *floe-ice*. When the floating pieces are crowded together, they make *ice-packs*, some of which are hundreds of miles across. Ice-packs are one of the obstacles to polar navigation. If the pack of one summer is still far enough north as winter comes on, to be caught in the freezing sea-water, it is frozen together into a solid mass.

Ice beneath the surface. The wedge-work of ice in the cracks of rock has already been mentioned (p. 40). When it is remembered that a freezing temperature occurs during some part of the year over about two-thirds of the earth, it will be seen that the total effect of the freezing of water in the pores and crevices of rock must be great in long periods of time. Water freezing in the soil sometimes "heaves" (displaces) walls if they do not go below the depth of freezing, and it sometimes "works up" stones and bowlders through the soil in cultivated fields. The frozen water in the soil has a protective effect also. It makes the soil solid for the time being, and so retards or prevents erosion by wind and water.

Snow. When the moisture in the upper air condenses at a temperature of less than 32° F., it commonly takes the form of snowflakes (Fig. 176). Snowflakes are not frozen raindrops; they are formed instead of raindrops when the temperature at which the water vapor in the air condenses is below the freezing-point. Snow falls in high latitudes during much of the year, and in middle latitudes during the winter season. Except on high mountains, little snow falls in low latitudes, and the little that does fall is soon melted.

While snow lies on the surface, it protects the vegetation beneath from great changes of temperature, and especially from the repeated thawings (by day) and freezings (by night) which are injurious to many plants, and it keeps the dust and sand beneath from being blown about by the wind.

Snow-fields. Where snow endures from year to year over any considerable area, it constitutes a *snow-field*. Snow-fields occur in mountains in nearly all latitudes; but the altitude which is necessary in the equatorial region is great (15,000 to 18,000 feet), that in the temperate region less, and that in the polar regions slight.

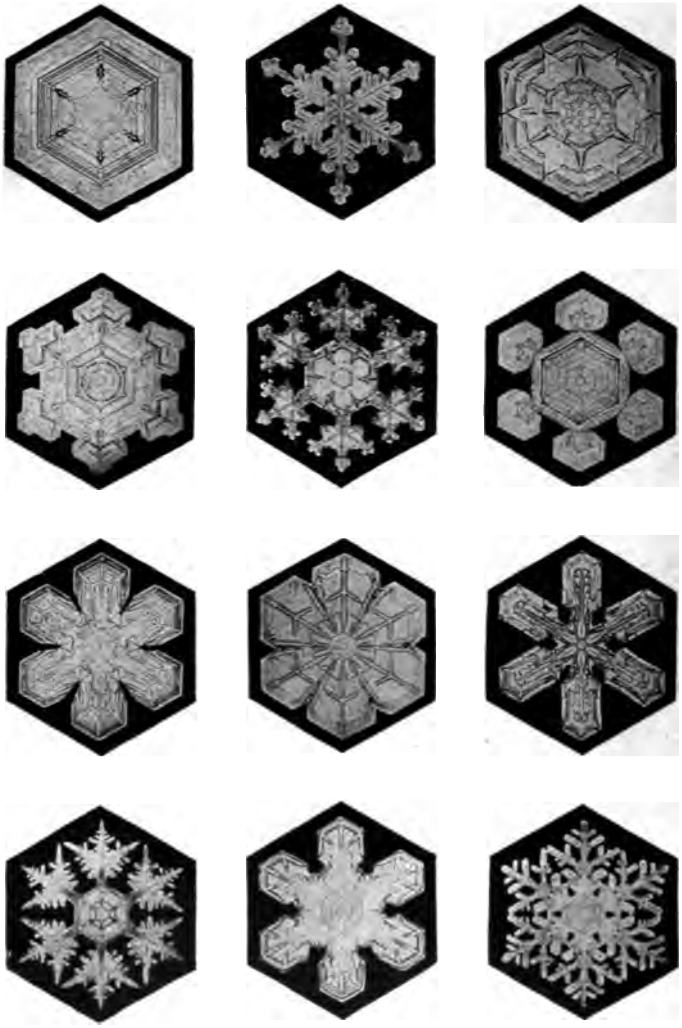


Fig. 176.—Photographs of snowflakes, enlarged. (Bentley.)

In the polar regions, indeed, snow-fields occur even down to sea-level.

Snow-fields are by no means rare even in the United States. They occur in the high mountains of California, Colorado, and Utah (rare), and in the high mountains of all the states farther north. The snow-fields of the more northerly states are more numerous and larger than those farther south. In the mountains north of the United States they are still larger, and in Alaska some of them attain great size. They occur also in the high mountains of most other countries, as in Mexico, in the Andes Mountains of South America, in the Alps (Figs. 177 and 178), the Pyrenees, the Caucasus, and the Scandinavian mountains of Europe, and in the Himalayas, and the other mountains of Asia farther north and northeast. They are found also in Africa, even very near the equator, but they are small, and limited to very high mountains.

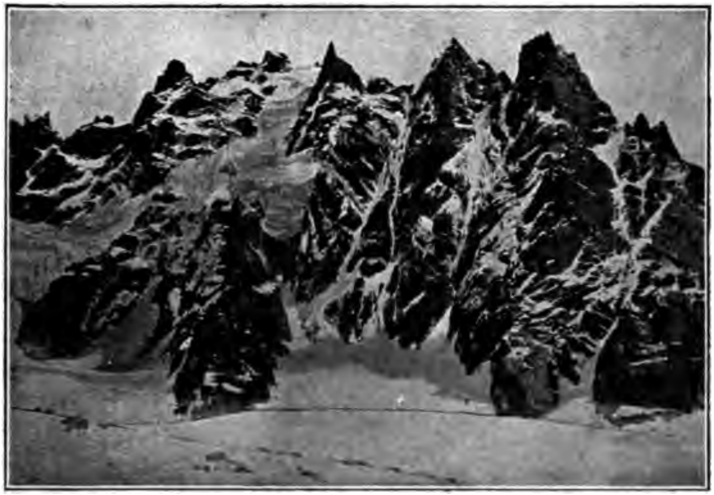


Fig. 177.—The edge of a snow-field. Fresh fallen snow lies in the depressions of the rock surface, and snow and ice lie at the base of the cliffs. Mount Blanc, Switzerland. (Tairraz.)

Besides these and other small fields of snow and ice, there are two great snow- (or snow-and-ice) fields in Greenland and Antarctica.

The snow-and-ice field of Greenland contains much more frozen water than all the mountain snow-fields mentioned above, and the ice-cap of Antarctica is much larger than that of Greenland. The total amount of snow and ice on all lands is probably as much as half a million cubic miles. If this amount of ice were melted and returned to the sea, the sea-level would be raised some 15 feet.

The snow-line. The *snow-line* in the mountains is the line above which the snow is not all melted in summer. Its position is influenced by several conditions, one of which is *temperature*. The influence of temperature is shown by the general fact that the snow-line is higher in lower (warmer) latitudes, and lower in higher (colder) latitudes. Temperature is, however, not the only thing which fixes the position of the snow-line, for in various mountains, for example the Himalayas, it is higher on the north side than on the south, although the temperature on the south side is much higher *than that on the north*.

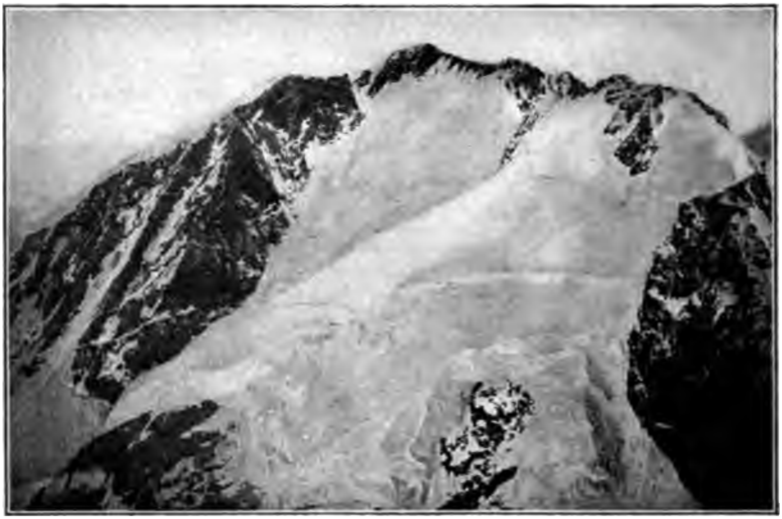


Fig. 178.—Nevé (granular snow) at an elevation of 4,052 meters, on the Swiss-Italian frontier. (Robin.)

Another factor is the *amount of snowfall.* The snowfall is much heavier on the south side of the Himalayas than on the north, and the thin cover of snow on the colder north slope is melted farther up the side of the mountain in summer, than the heavier cover on the warmer south slope.

Some other factors also influence the position of the snow-line, but temperature and snowfall are the most important. The following table shows the position of the snow-line at a few points:

Bolivian Andes, west side,	Near Equator,	About 18,500 feet.
Bolivian Andes, east side,	Near Equator,	About 16,000 feet.
Chilean Andes,	Lat. 33° S.,	About 12,800 feet.
Himalayas, north side,	Lat. about 28° N.,	About 16,700 feet.
Himalayas, south side,	Lat. about 28° N.,	About 13,000 feet.
Caucasus Mountains,	Lat. 40°+ N.,	About 8,300–14,000 feet.
Pyrenees Mountains,	Lat. 40°+ N.,	About 6,500 feet.
Lapland,	Lat. 70° N.,	About 3,000 feet.
Alaska,	Lat. about 60°	About 5,500 feet.
Greenland,	Lat. 60°–70° N.,	About 2,200 feet.

Ice-fields. Every large snow-field is also an ice-field, for where snow accumulates to great depths and lies long upon the surface, it is changed to ice. The beginning of this change may be seen in the snow a few days after it falls, for it soon loses its light, flaky character and becomes granular, so that it feels harsh to the hand. The change is very distinct in the last banks of snow in the spring. They are made up of coarse grains (granules) of ice, sometimes as large as peas. The change from flakes of snow to granules of ice is due, in part, to the melting of the snow and the refreezing of the water. If there is much snow, it is compressed by its own weight, and after being compacted in this way, the freezing of the sinking water binds the granules together. By this and perhaps other processes, the larger part of every thick snow-field becomes an ice-field merely coated over with snow.

GLACIERS

When the amount of ice developed from snow becomes great enough, it begins to move out by a sort of spreading motion from the place where it was formed. When it begins to move, it becomes

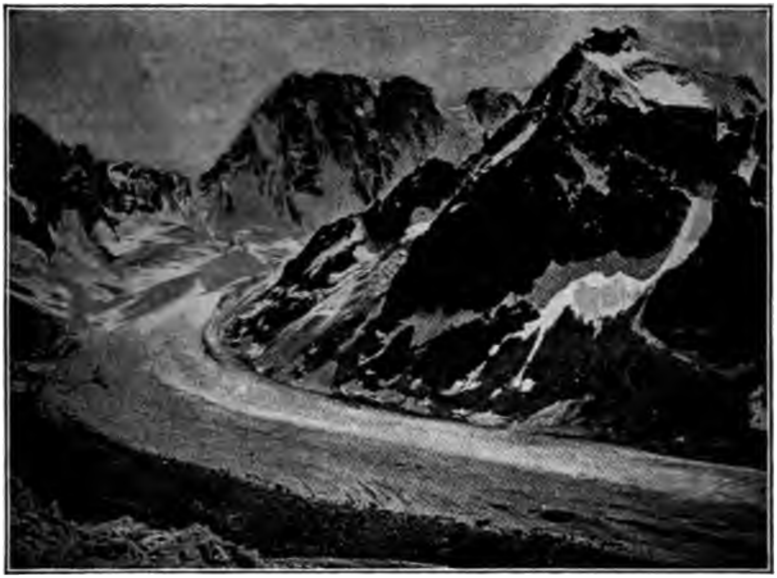


Fig. 179.—Les Chaux Glacier, where it comes out of its basin of accumulation, Switzerland. (Neurdein.)

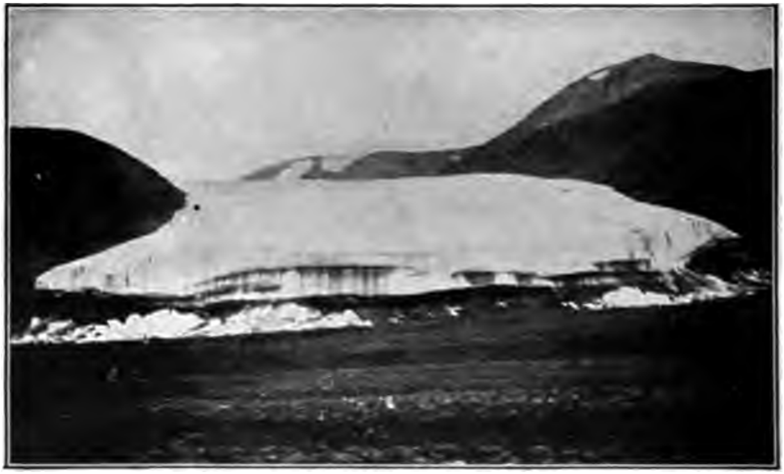


Fig. 180.—The spreading end of a glacier, North Greenland.

a *glacier*. Not all snow-fields give rise to glaciers, but all glaciers have their sources in snow-fields. The distribution of glaciers is therefore much the same as that of snow-fields.

Types of glaciers. Glaciers have various shapes, depending on the amount of ice and on the shape of the surface where they are.

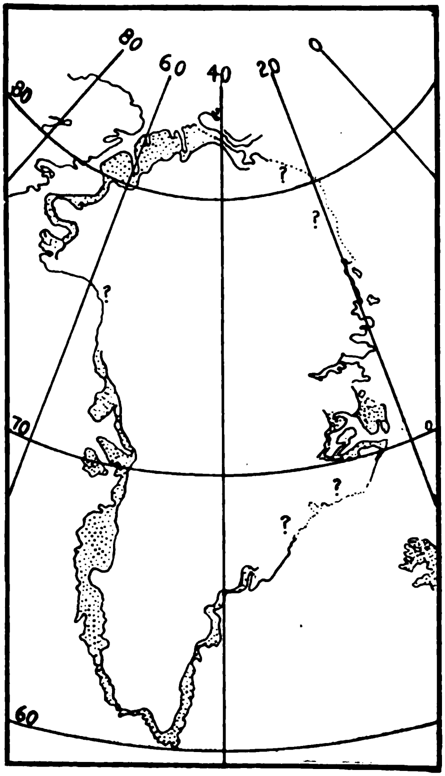


Fig. 181.—Map showing the ice-cap of Greenland. Only the borders of the island are free from ice.

If the snow-field which gives rise to a glacier is at the upper end of a mountain valley, the ice moves down the valley. Such glaciers are called valley glaciers (Fig. 179). Glaciers of this type are not all alike. Those of the type found in the Alps Mountains and in other mountain valleys of middle latitudes are called *alpine* glaciers, while those of polar regions, having much steeper sides and ends, are *high-latitude* glaciers (Fig. 180).

In high latitudes, snow-fields and the fields of ice to which the snow-fields give rise sometimes lie on plains or plateaus. When the ice in such situations begins to spread, it moves in all directions from its center. Such glaciers may be nearly circular, and are called *ice-caps* or *ice-sheets*. The main ice-caps of Antarctica and Greenland (Figs. 181 and 182) are large, but small ones of the same type are found on various promontories along the coast of Greenland, on Iceland (Fig. 183), and on some Arctic islands.

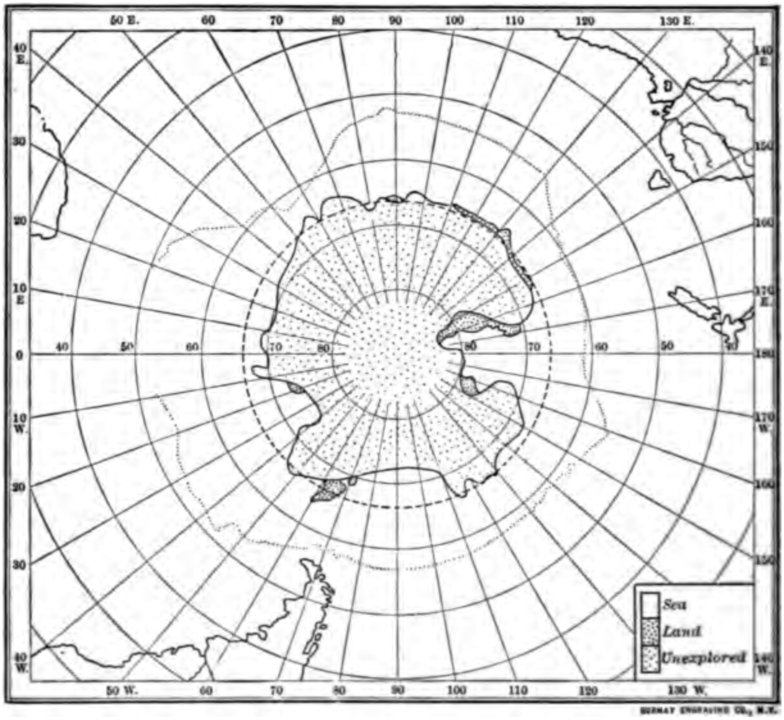


Fig. 182.—Map of Antarctica. The dotted line represents the approximate limit of abundant floating ice. (After Bartholomew.)

Glaciers sometimes occur at the bases of mountains, being formed by the union of the spreading ends of valley glaciers. Such glaciers are *piedmont glaciers*. Another type of small glaciers,

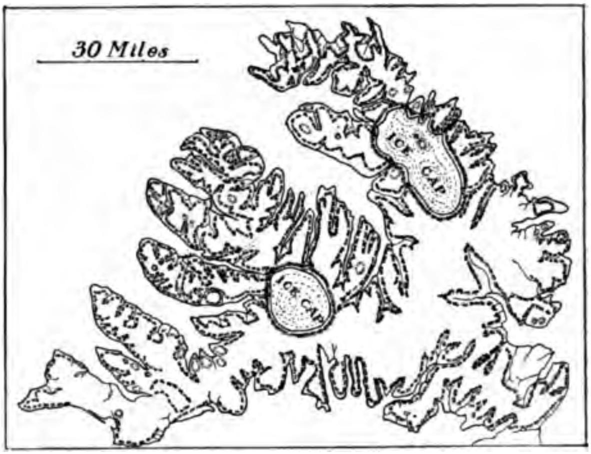


Fig. 183.—Small ice-caps in the northwestern part of Iceland.

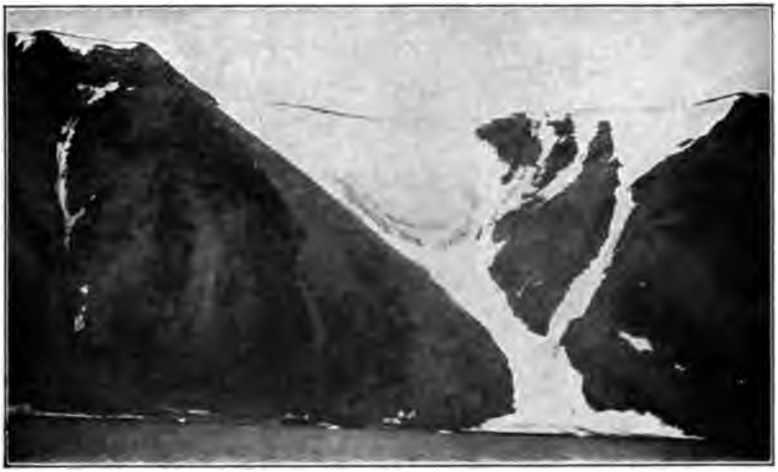


Fig. 184.—A cliff glacier, coast of North Greenland. The height of the cliff is perhaps 2,000 feet. The water in the foreground is the sea.

called *cliff glaciers*, is shown in Fig. 184. Cliff glaciers grade into valley glaciers.

Of these types, valley glaciers are most common and most familiar, but the large ice-caps contain much more ice.

The Valley Glacier

The general form of a valley glacier (Fig. 185) is determined chiefly by the valley in which it lies. If the valley is crooked the glacier turns to match it, and if the bottom is very uneven the surface of the ice is uneven too. Valley glaciers have sometimes been called "rivers of ice." but the differences between glaciers and rivers are so much greater than their likenesses that this definition is not a good one.

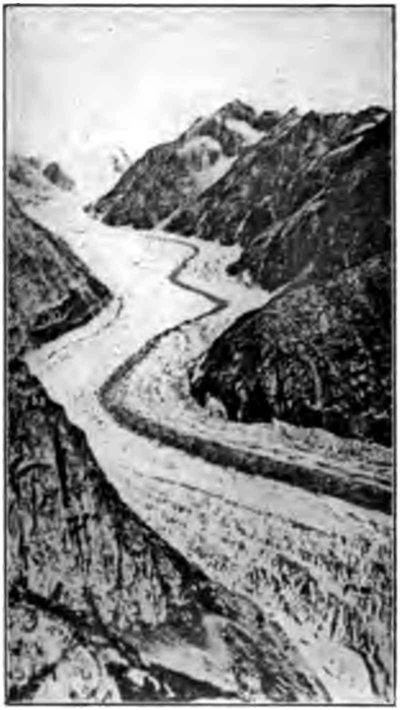


Fig 185. Aletsch glacier, Switzerland.

The surface. The upper end of a valley glacier is in the snowfield, and is always covered with snow (Fig. 179). The lower end may be covered with snow in winter, but not as a rule in summer. Some glaciers carry so much rock rubbish on their surfaces as to almost conceal the ice, especially near their lower ends.

The center of a valley glacier is often a little higher than its side, and its surface may be smooth (Fig. 179) or rough (Fig. 186). The causes of roughness are several. 1. In many cases the ice is cracked, and the cracks, or *crevasses*, frequently gape. One cause of the crevasses is the movement of the brittle ice over *an uneven bed* (*Fig.* 187). Crevasses formed in this way usually run across the glacier from side to side. Some glaciers have crevasses parallel to their sides or oblique to them, and such crevasses

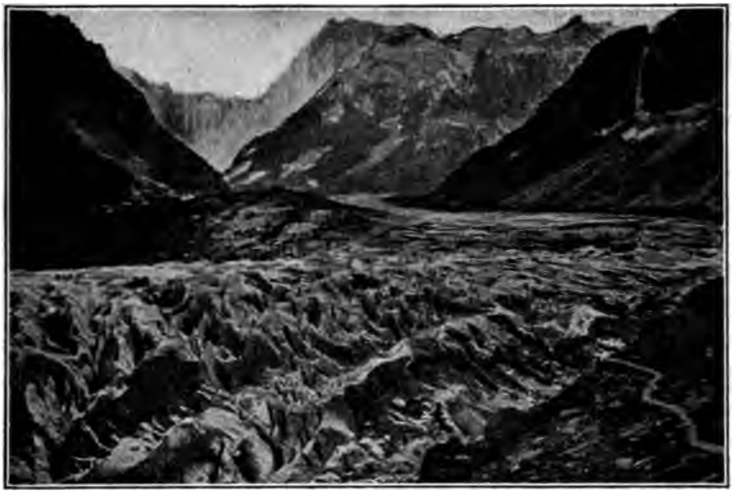


Fig. 186.—The Mer de Glace, Switzerland, showing the very much broken surface of the ice, and the curves of the glacier.

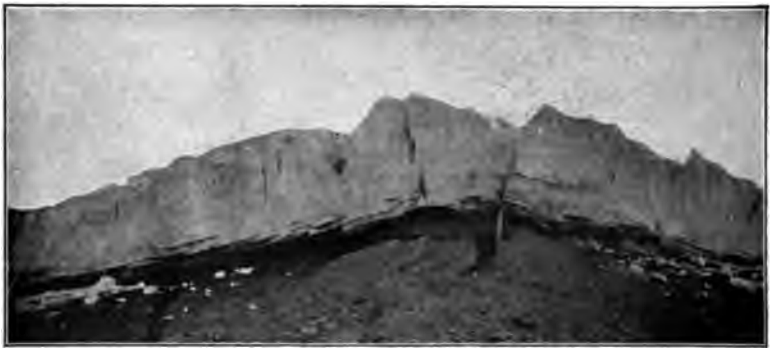


Fig. 187.—Crevassed glacier, the cracking being due to a change in grade of the bed. North Greenland.

are due to other causes. The breaking of the ice as it moves is one of the many ways in which a glacier differs from a river.

The forward movement of the ice often tends to close up the crevasses, but their sides rarely come together so as to leave the

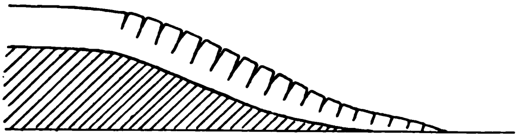


Fig. 188.—Diagram to illustrate the effect of an uneven bottom on the crevassing of the glacier. The figure represents, in a general way, the results which would appear if there were no melting.

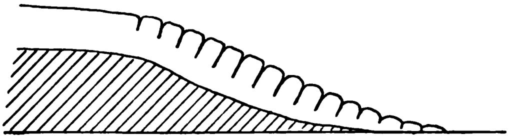


Fig. 189.—The same as the last except that melting has taken place, and so prevented the closing up of the crevasses.

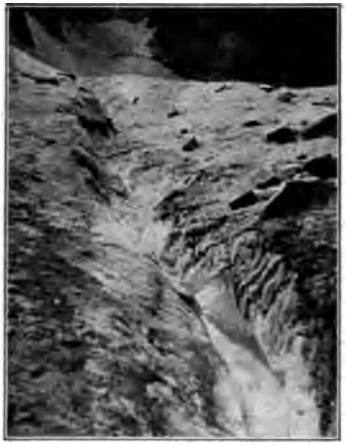


Fig. 190.—Valley of a superglacial stream in the Bighorn Mts. (Blackwelder.)

surface smooth. While a crevasse is open, the sun's rays and the sun-warmed air enter it and melt the ice on its sides. This widens the crevasse, and widens it most at the top, so that when the movement tends to close it, the opposing faces rarely fit together. This is illustrated by Figs. 188 and 189.

2. Valley glaciers often extend far below the snow-line, and their lower ends are within the region of active melting during the summer. Some of the surface water sinks into the ice, but some of it forms little streams which flow on the ice until they reach a crevasse or the edge of the glacier. These streams make little valleys in the ice (*Fig. 190*), and so help to make its surface rough.

3. The stony and earthy debris which many valley glaciers carry on their surfaces also makes them uneven. Large stones protect the ice beneath from melting, and therefore come to stand on pillars of ice (Fig. 191), after the surface about them is melted away.

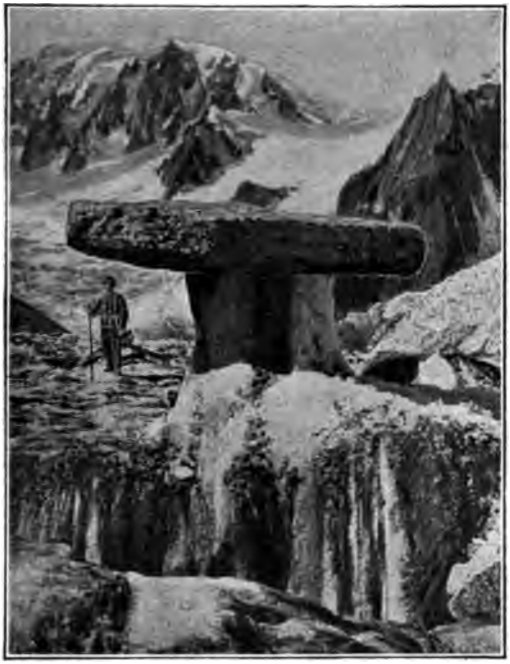


Fig. 191.—A glacial table, due to the protection of the ice beneath the flat stone from the rays of the sun. Talèfre Glacier.

Quantities of debris of any sort have the same effect, by shielding the ice beneath from the sun's rays. Small stones on the surface of the ice have the opposite effect. Rock absorbs heat better than the ice does, and thin pieces of rock are warmed through, and melt their way down into the ice more rapidly than the sun melts the surface about them. Dust is often blown on the ice, and if it gathers in patches they have the same effect as thin pieces of stone. The depressions to which the dust gives rise are known as dust-wells

(Fig. 193). Dust-wells are sometimes so close together that one must watch his steps in walking over glacier ice which is otherwise smooth. The wells are rarely more than a few inches deep.

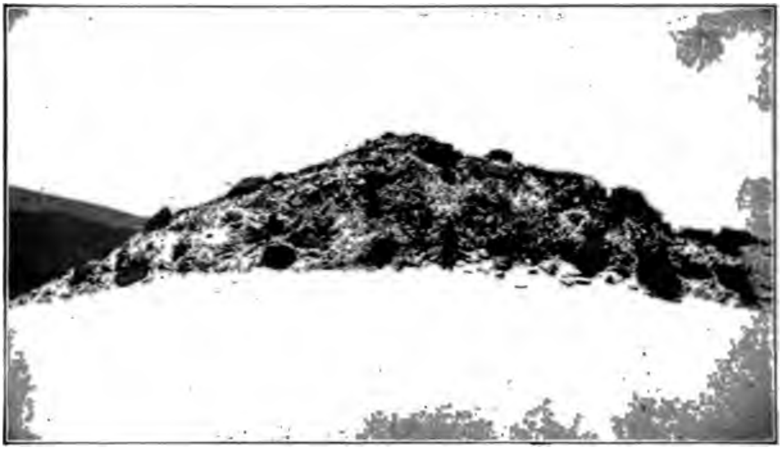


Fig. 192.—A mound of debris on the edge of the Greenland ice-cap, north of Cape York. The mound is mostly of ice which the debris has protected from the sun.

Problem. By the help of Fig. 193, determine what it is which limits the depth of a dust-well.

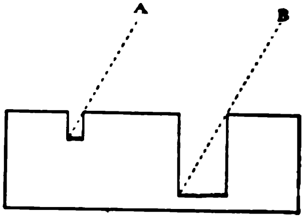


Fig. 193.—Diagram to illustrate the fact that dust-wells of larger diameter may be deeper than those of smaller diameter. The slanting lines represent the direction of the sun's rays when the sun is highest.

Movement

Waste and supply of ice. The ice of a glacier is continually wasting, (1) by melting at the surface, especially in summer, (2) by melting below the surface, and (3) by evaporation. But in spite of this constant waste, glaciers often remain about the same size year after year. This shows that there must be some source of supply to replace the waste. The supply is from the snow-fields, *from which the ice creeps* down the valleys until it reaches a place so low and so warm that the melting at the end balances the forward motion.

The movement of a glacier is so slow that it cannot be seen. It was first known by observing (1) that the ends of glaciers were sometimes farther down the valleys than they were at earlier times; and (2) that familiar objects near the ends of glaciers were sometimes overturned and pushed forward by the ice.

Rate of movement. After the fact of movement was known, means were devised for measuring its rate. Rows of stakes were set across a glacier in a straight line (Fig. 194). After a time they were found to have moved down the valley, and in most cases those in the central part of the glacier were found to have moved farther than the others, as shown in the figure.

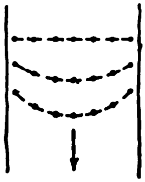


Fig. 194. Diagram of the surface of a glacier, showing how a row of stakes, set straight across the glacier, becomes curved as the ice moves forward. The curvature of the line of stakes shown in the figure is not seen distinctly until weeks or months after the stakes are set.

The rate of movement of numerous glaciers has been measured in this way or in some other. The rates range from one so slow that it is hard to measure, up to several feet a day. One very large glacier in North Greenland has been thought to advance 100 feet a day; but this is not an actual measurement, and is far beyond the rate of any glacier whose motion is known. Of those whose rate of advance has been measured, few move more than two feet a day, and very few as much as seven feet.

Conditions affecting rate of movement. The rate of movement appears to depend chiefly on (1) the depth of the moving ice, (2) the slope of the surface over which it moves, (3) the slope of the upper surface of the ice, (4) the topography of its bed, (5) the temperature, and (6) the amount of water in the ice. Great thickness, a steep slope, a smooth bed, a high (for ice) temperature, and much water favor rapid movement. Since temperature and amount of water vary much from season to season, the rate of movement for any given glacier varies much during the year, and is greater in summer than in winter.

Nature of glacier movement. It was formerly thought that the ice flowed somewhat as a stiff liquid flows, and this view is, perhaps, the one most widely held. It seemed at first to be supported by the fact that the movement was most rapid at the top and in the center, as in the case of a river. The spread of the end of a glacier, too (Fig. 180), as it moves out from its mountain valley to the plain beyond, was thought to suggest flowage. Furthermore, various experiments have been performed with ice showing that a bar of it may be bent or moulded into almost any shape, if it be pressed slowly enough through long periods of time. But in spite of all the facts and experiments which suggest the fluidity of ice, it is very doubtful if its real motion is flowage.

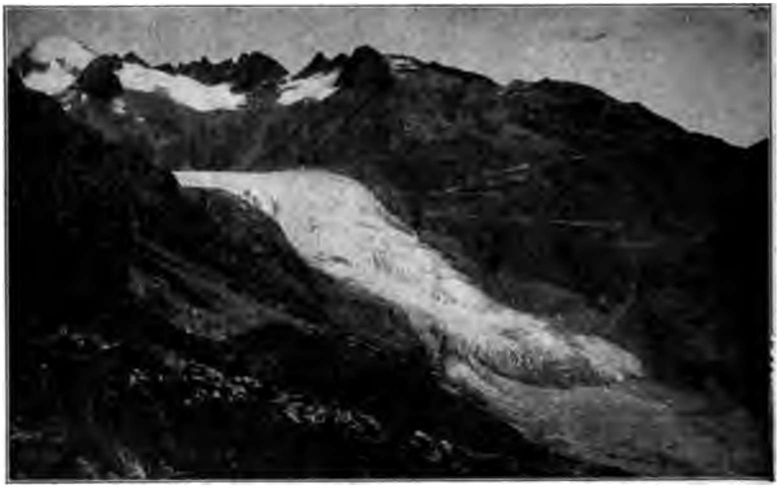


Fig. 195.—The Rhone glacier. (Photo. by Reid.)

It has already been noted that a glacier often cracks when it passes over irregularities of bed. The ice also cracks open when the end of a glacier spreads (Fig. 195), and if the spreading of the end shows fluidity, we must assume that the ice flows until it cracks open. But fluids do not crack open. These and many other considerations which need not be discussed here have led to the view that the resemblance between glacier motion and the motion of a stiff liquid is more seeming than real.

It is probable that *the melting and refreezing of its substance has much to do with glacier motion.* When water sinks into the glacier and freezes again, it expands and crowds the ice all about it. The force of the crowding is illustrated by the familiar fact, already referred to, that strong vessels are broken when water freezes in them. The freezing of the water which has sunk into the ice must have the effect of moving the ice, and the movement must be chiefly down the valley, for gravity helps motion in this direction, and hinders it in all others. Furthermore, the water before refreezing moves not only down toward the bottom of the ice, but often, at least, toward the lower end of the valley as well. The *flow of the water is therefore a way of transferring the ice* of the glacier down-valley. More or less ice is melted from time to time within

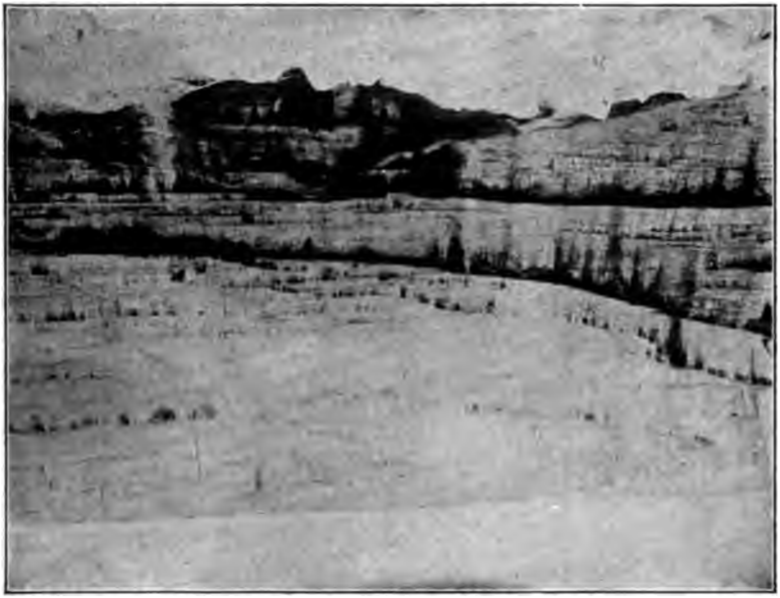


Fig. 196.—Shearing planes in ice. A Spitzbergen glacier, seen from the side. (Hamberg.)

the glacier, and this water on refreezing has the same effect as that which sinks in from the surface.

The ice of a glacier sometimes slides, for in some cases it may be seen that portions of the ice have slidden or *sheared* over other parts (Fig. 196). This is best seen in the glaciers of high latitudes, where the structure of the ice may be well seen in the vertical edges and ends of the glaciers. Under some conditions, a glacier probably slides over its bed, but such sliding is not believed to be a principal element in glacier motion.

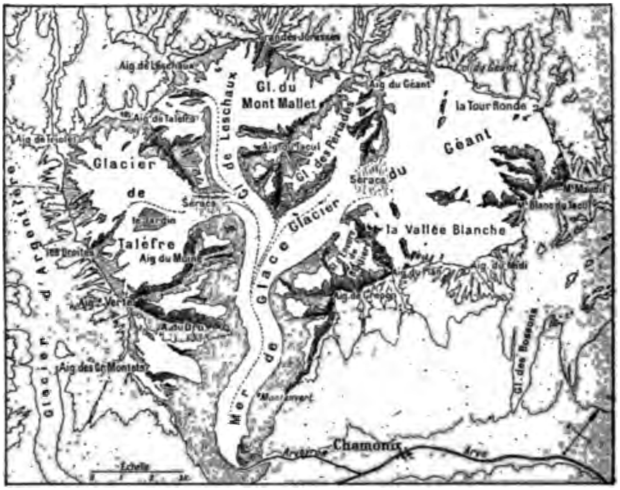


Fig. 197.—A type of a glacier system. Snow-fields above send out tongues of moving ice which unite to form the *Mer de Glace*, which is a well-defined valley glacier. The white part represents snow and ice. (Robin.)

Size. There are in the Alps nearly 2,000 glaciers, only one of which has a length of ten miles. Less than 40 have a length of five miles, while the great majority are less than one mile long. Some of them are but a few hundred feet wide, and few of them are so much as a mile wide. The thickness of ice is rarely known, but even where thickest it is but a few hundreds of feet.

Larger alpine glaciers occur in the Caucasus Mountains and in *Alaska*. *Seward* Glacier in Alaska is more than 50 miles long, and three miles wide at the narrowest part. The glaciers of the western mountains of the United States south of Alaska are mostly shorter than the longer glaciers of the Alps. Many of them are cliff glaciers, or intermediate between valley glaciers and cliff glaciers.

Disposition of surface debris. The rock and earthy debris on a glacier is sometimes scattered irregularly over the surface, but it is often arranged in definite belts. When these are near the sides they are called *lateral moraines;* when near the middle, *medial moraines* (Figs. 185 and 198). When there is much debris on the ends of a glacier it makes *terminal moraines.*

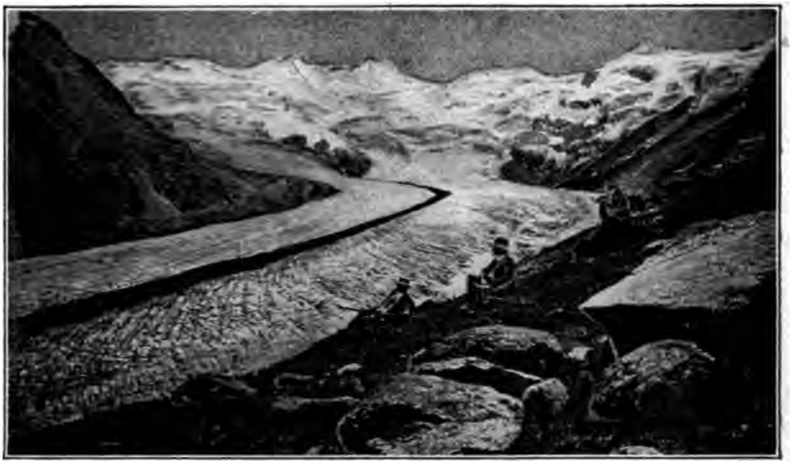


Fig. 198.—The medial moraine of the Roseg Glacier, Switzerland.

Ice-caps

As already stated, ice-caps may lie on plains or plateaus, and may be large or small. Large ones may cover valleys and hills alike, and very large ones are sometimes called *continental glaciers.* The ice-caps of Greenland and Antarctica are the only ones of great size.

The area of Greenland (Fig. 181) has been variously estimated at from 400.000 to 600,000 square miles, and all except its borders is buried beneath one vast field of ice and snow Except on a narrow border of a mile or so at the edge of the ice-sheet, not even a bowlder or a pebble relieves the great expanse of white. Travelers across the great ice-sheet tell us that this unbroken whiteness becomes almost unbearable.

The thickness of the Greenland ice is not known, but where thickest, it is probably thousands of feet. Near its margin the ice is much crevassed; but the interior is comparatively smooth so far as now known. The ice of this great field is creeping slowly outward. The rate of movement has never been measured, and is probably not the same at all points, but it has been estimated not to exceed a foot a week.

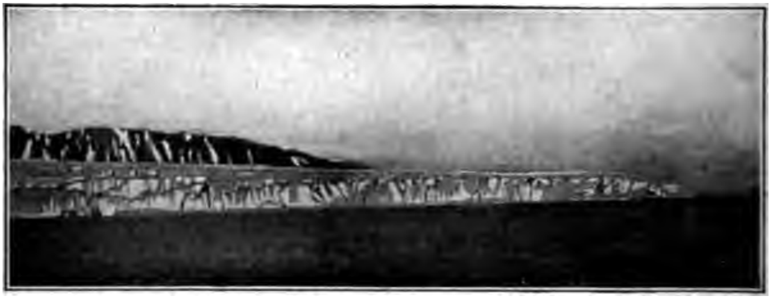


Fig. 199. The end of a glacier in Spitzbergen. (Rabot.)

This ice-cap is, in one sense, more of a desert than the Sahara, since it is inhabited even less than that desert by plants and animals. There are, it is true, tiny red plants upon it at various points about its border. Taken singly, they are too small to be readily noticed, but they sometimes occur in such multitudes as to give the snow a distinctly red color, known as "red snow."

Where the edge of the Greenland ice-cap lies a few miles back from the coast, the rock plateau outside it has numerous valleys leading down to the sea. Where the edge of the ice-cap reaches the heads of these valleys, ice moves down them, making valley glaciers. Many of them reach the sea (Fig. 199), where their ends are broken off and floated away as icebergs. This is the source of most of the bergs (Fig. 200) seen by the steamers which cross the

North Atlantic. Some of them are so large that they float far to the south before they are melted. While the number of valley glaciers in Greenland is very large, the total amount of ice in them is small compared with that in the great ice-cap glacier from which they move.

The Antarctic snow-and-ice cap is far more extensive than that of Greenland, but its area is not so well known (Fig. 182). It is probably several million square miles in extent, and the thickness of its ice probably far exceeds that of Greenland. The ice descends to the sea at many points, and huge blocks of it become icebergs. Of these bergs in the southern ocean we know little, for few important lines of ocean steamers traverse those waters.

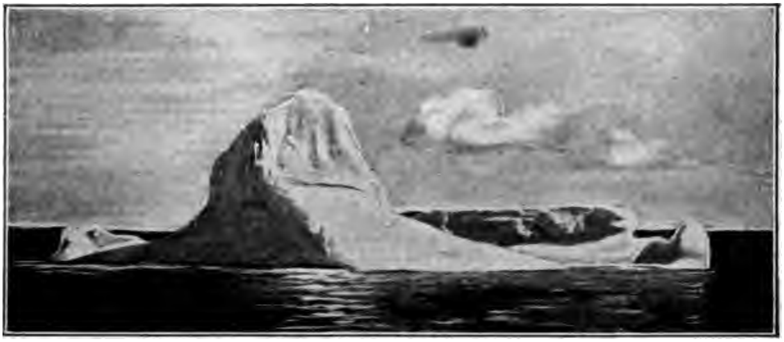


Fig. 200.—An iceberg. (Robin.)

Piedmont Glaciers

In Alaska, a number of alpine glaciers come down adjacent valleys in the St. Elias range and spread out upon a low plain at its base. So much do their ends spread, that they unite to form a single body of ice, 70 miles long and 20 to 25 miles wide, called the *Malaspina Glacier*. Its area is greater than that of the state of Delaware. Its central portion is free from rock debris, but is interrupted by thousands of deep, wide cracks. On warm summer days hundreds of rivulets flow in channels of clean ice until they lose themselves in yawning crevasses. The deep roar of some stream in its tunnel far below the surface is frequently heard.

Nearer the margin, where the ice is not so broken, there are many small ponds with high walls of ice. A belt along the margin five miles or less in width is covered by rocky and earthy debris, and parts of it are clothed with vegetation. The undergrowth is here so thick that travelers have to cut their paths, and on the edge of the ice there are trees three feet in diameter (Fig. 201). The ice is probably 1,000 feet thick. Another large but unexplored glacier of the same type lies a few miles west of the Malaspina, and others occur about North Greenland. Curious as they are, piedmont glaciers are of slight importance.

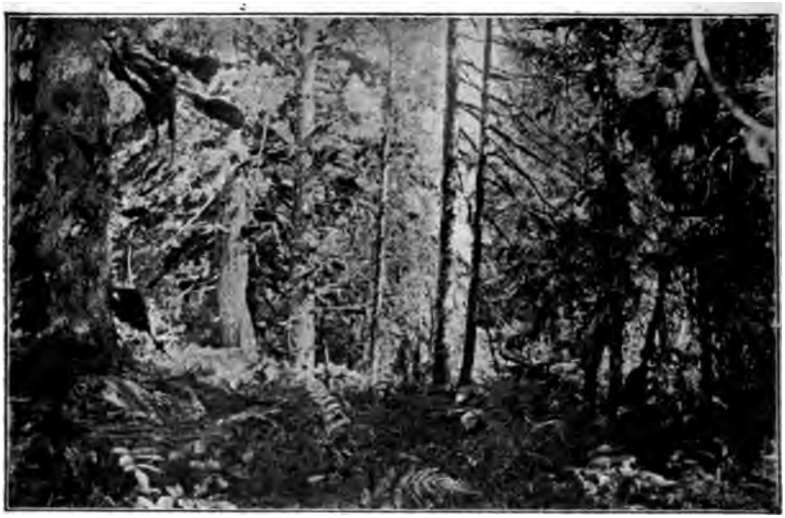


Fig. 201. —Forest on the southern border of Malaspina glacier. (Russell.)

THE WORK OF GLACIERS

Glaciers do a twofold work: they erode the surface over which they pass, and they deposit the material which they get by erosion. The ice gets its load in many ways.

Erosion

1. As the snow-field accumulates, it often lies upon an uneven *surface covered* with loose pieces of rock. All these pieces are cov-

ered and enclosed by the snow, and when it becomes ice and begins to move, they are carried along with it. Glacier ice, therefore, often has some load when it begins to move.

2. Where the snow and ice bury projecting points of bed-rock (Fig. 177), the ice tends to break them off when it moves. If they are too strong to be torn away bodily, their surfaces are worn and smoothed. The bed-rock over which and against which a glacier advances is often in blocks, partially separated from one another by joints (Figs. 81 and 202), and the moving ice sometimes removes large blocks from its bed, especially from cliffs over which it descends, and from jagged walls of rock against which it crowds. Fig. 202 represents a cliff — the Palisades, west of the Hudson River. Glacier ice once passed over this ridge from northwest to southeast, and carried masses of rock from the cliff over to the area where New York City and Brooklyn now stand.

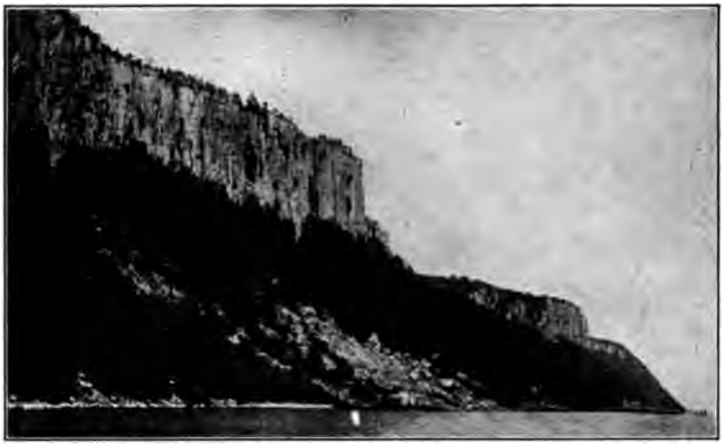


Fig. 202.—The face of the Palisade Ridge, west of the lower Hudson. The rock is jointed, as shown by the vertical lines on the cliff face. Ice moving over this from left to right would break off large quantities of rock.

3. As a glacier creeps out over surfaces covered with soil or other mantle rock, the ice freezes to the soil; that is, the ice above the ground becomes united to the ice in the soil. This union is brought about, in part at least, by the freezing of descending water.

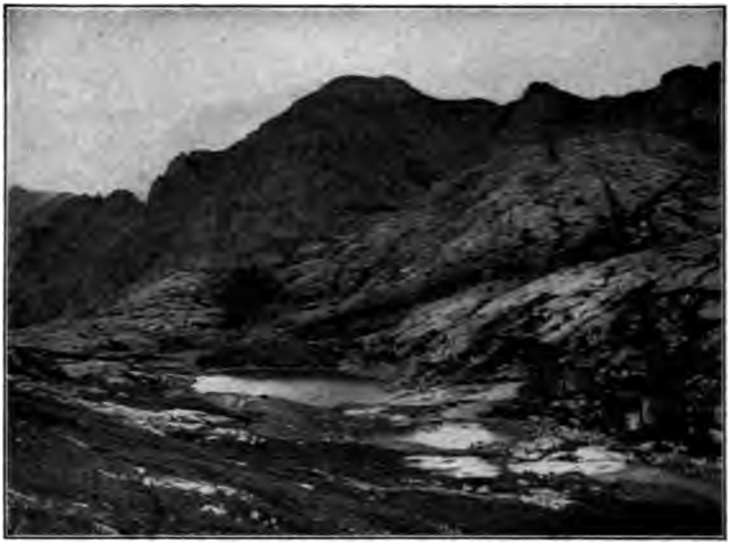


Fig. 203.—A mountain valley cleared of all earth and loose rock by a glacier which once passed through it. The moving ice also smoothed all the projecting points of rock. A type of a glaciated mountain valley in the higher part of the Needle Mountains, Colorado. (U. S. Geol. Surv.)

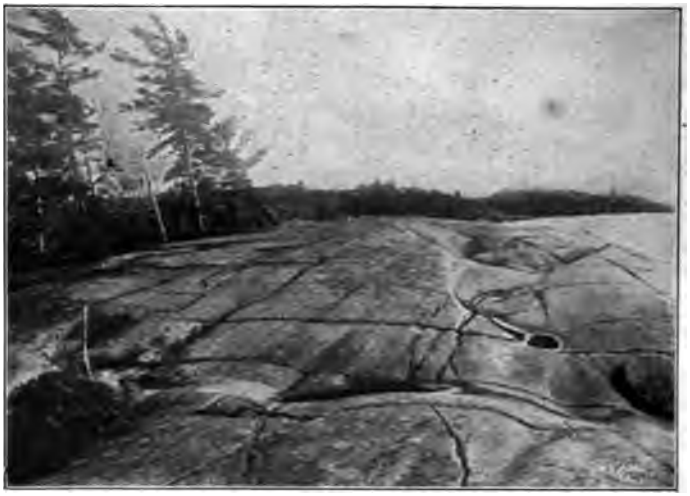


Fig. 204.—Ice-worn rock, Bell's Island, Lake Huron. (Bell.)

After this has taken place, further movement causes some of the soil to be carried forward by the ice.

A glacier, therefore, cleans off the loose debris from the surface (Fig. 203), and breaks or wears off projecting points of the surface over or against which it passes. Clean ice, moving over smooth, solid rock, would erode little, but ice carrying pieces of rock in

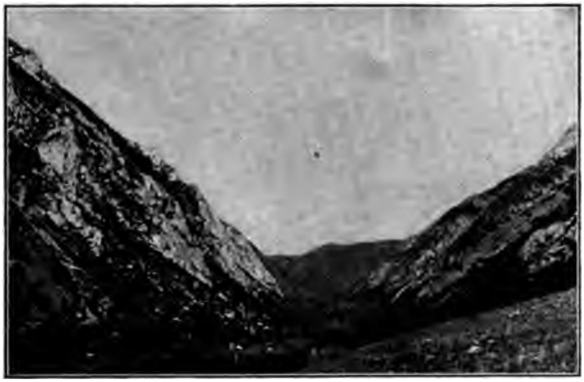


Fig. 205.—A mountain valley which has been strongly glaciated; Uinta Mountains. (Church.)

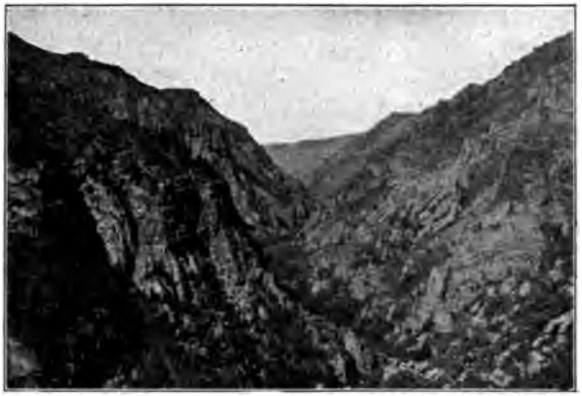


Fig. 206.—A mountain valley in the same range as the last, but not glaciated. (Church.)

its bottom wears the surface, even when it is smooth and of solid rock.

Valleys through which glaciers pass are widened and deepened,

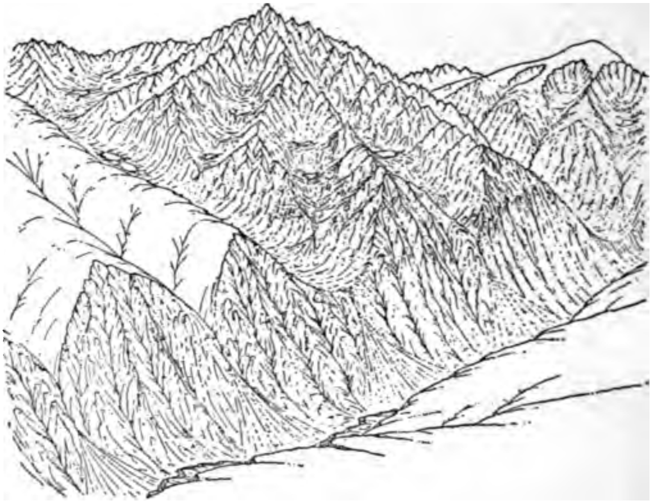


Fig. 207.—Diagram showing hanging valley. (Davis.)

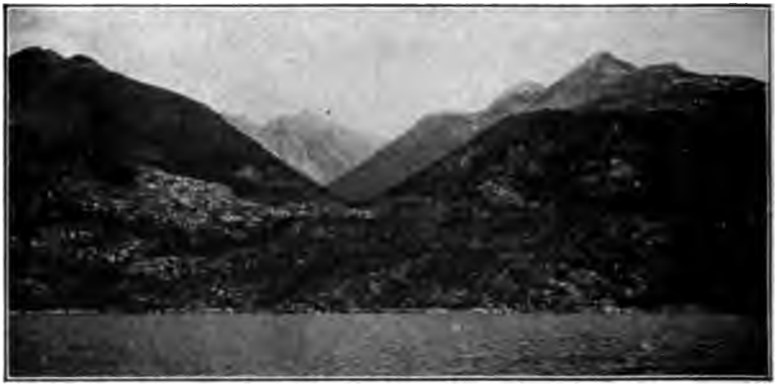


Fig. 208.—A hanging valley near Lake Kootenay. (Atwood.)

and their walls made smoother (compare Fig. 205 with 206). The *deepening of a mountain* valley by glacial erosion sometimes brings about a curious relation between it and its tributaries. The effect is illustrated by Figs. 207 and 208, in which the lower ends of the tributary valleys are much higher than the valleys which they

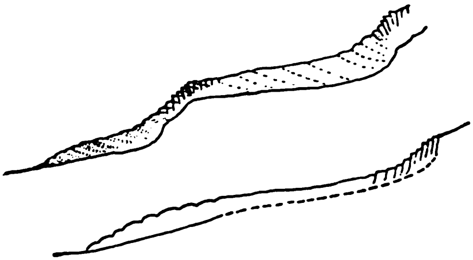


Fig. 209.—Diagrammatic longitudinal sections of glaciers. (Heim.)

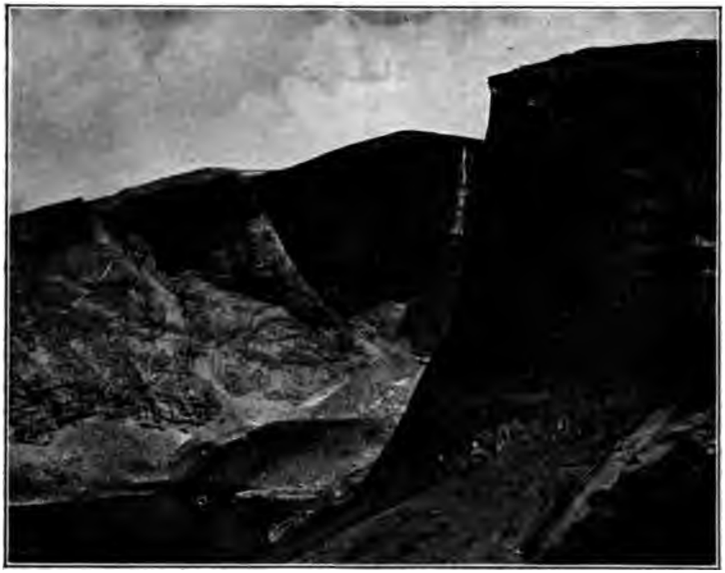


Fig. 210.—A cirque in the Bighorn Mountains; head of the West Tensleep Valley.

join. Such valleys are called *hanging valleys*. They abound in the mountains of the western part of the United States, and in other mountains where glaciers formerly existed. The tributary may be left hanging because the main valley is deepened by glacial erosion, while the tributary is not, or in some cases both the main and the tributary valleys are deepened, but the former much more than the latter.

A mountain glacier often descends rapidly near its head (Fig. 210), and the bottom of this steep descent is the site of great erosion.

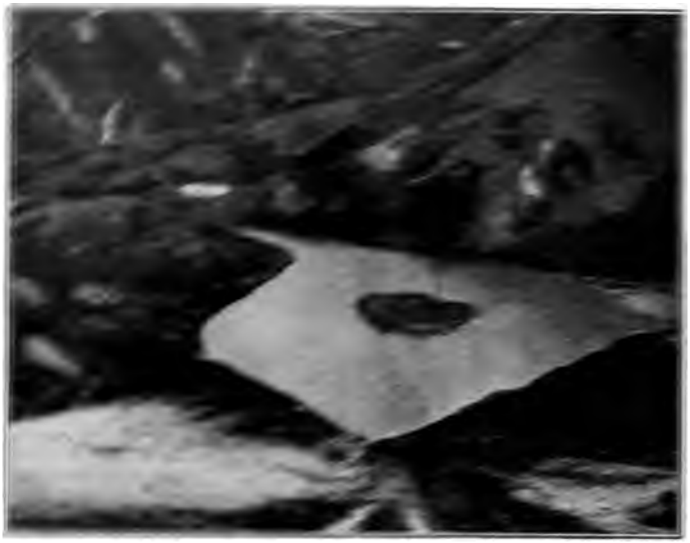
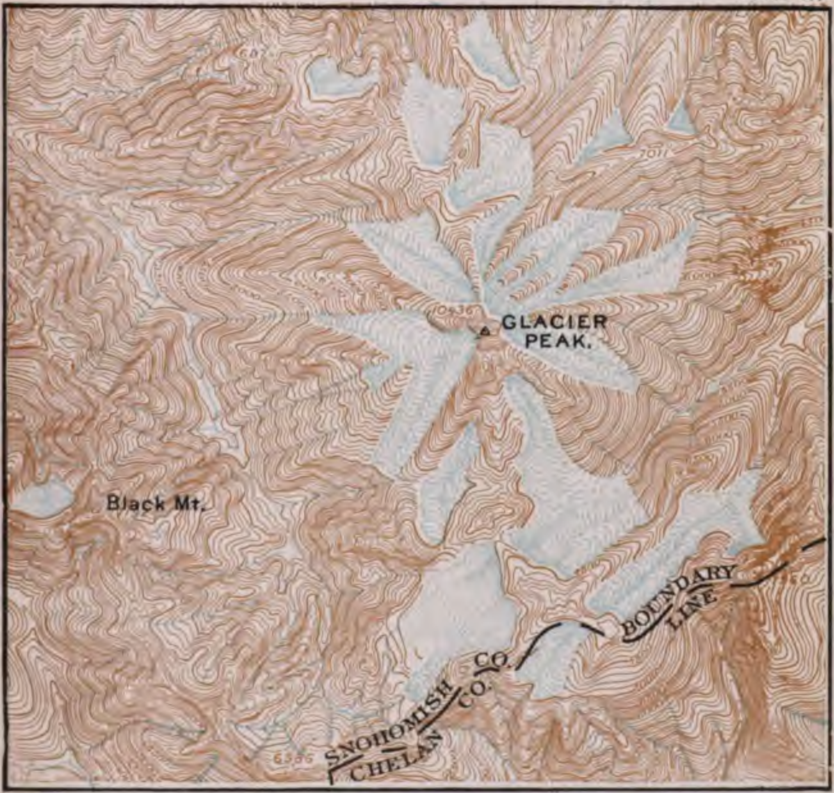


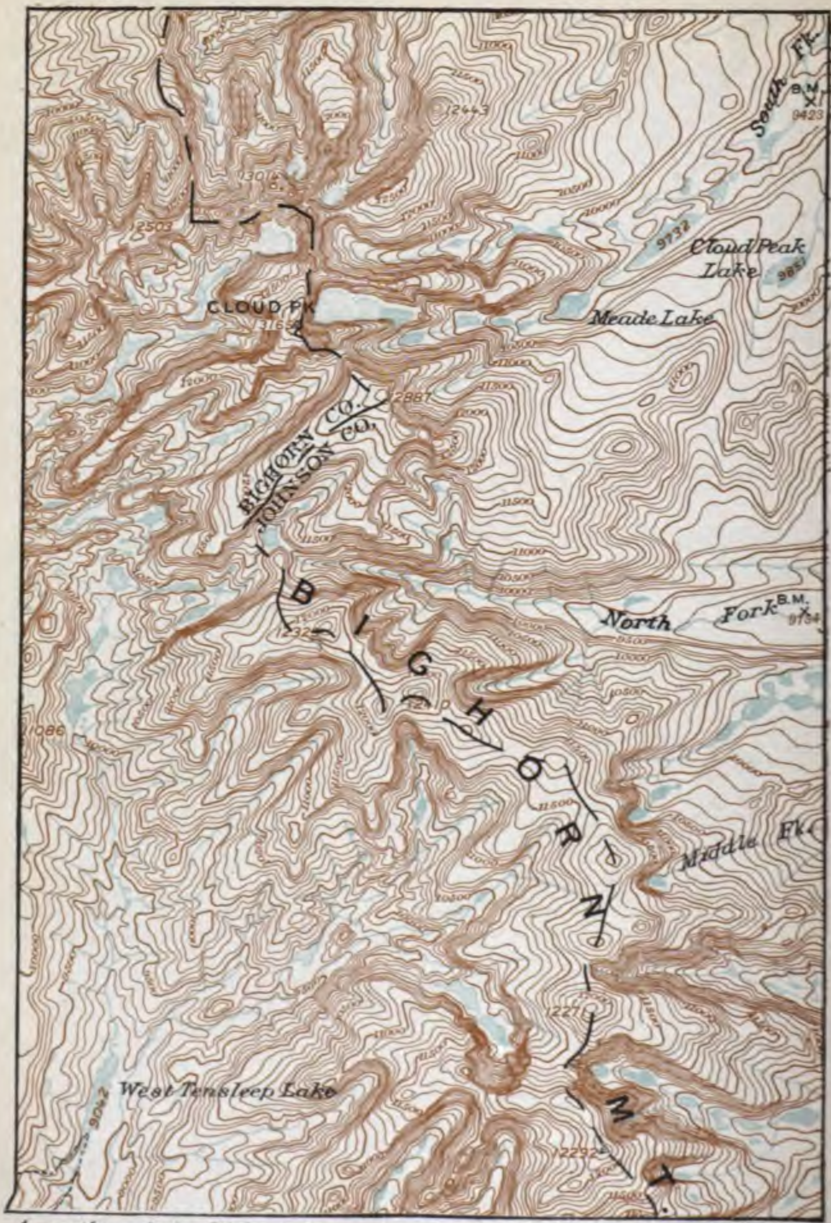
Fig. 211. — Island lake near Telluride, Colorado. The lake is about 12,500 feet above sea-level. (Hole.)

Great erosion here carries the head of the valley back farther and farther into the mountain, and at the same time makes it deeper and wider (Fig. 210 and Pl. XVI). The big, blunt, steep-sided heads of valleys developed by the erosion of valley glaciers are *cirques*. Cirques are numerous in the Uinta, the Bighorn, and many other mountains of the West in which there were formerly large glaciers. In the bottoms of the cirques there are often basins in the solid rock. Not a few of the beautiful little lakes (Figs. 210 and 211) which add so much to mountain scenery are in such basins.



Glaciers on Glacier Peak, Washington. The glaciers are shown in blue. Scale about 2 miles per inch. (Glacier Peak, Wash., Sheet, U. S. Geol. Surv.)

PLATE XVI



A portion of the Bighorn Mountains, showing glaciated valleys, the heads of which are in many cases cirques. Scale about 2 miles per inch. (Cloud Peak, Wyo., Sheet, U. S. Geol. Surv.)

Cirques and hanging valleys are often found in the same region, and both are common in mountains which have the general features shown in Fig. 205.

The effect of ice-sheets on valleys is not so striking. Great ice-sheets override hills and divides as well as valleys. The hills overridden are worn down and smoothed off (Figs. 213 and 214), and the wear is often greatest on the side of the hill against which the ice moves (Fig. 213). It is probable that the valleys through which the ice of a large ice-cap moves are deepened more than the neighboring hilltops are lowered. In this case, the relief of the surface is increased by glacial erosion, but its roughness may be decreased, especially by the wearing away of many little irregularities.

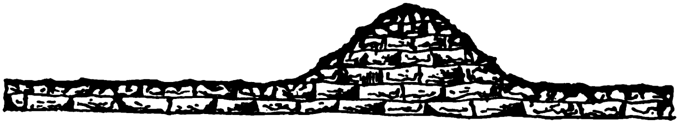


Fig. 212.—Diagram representing a hill unworn by ice, and the irregular contact of soil and rock.

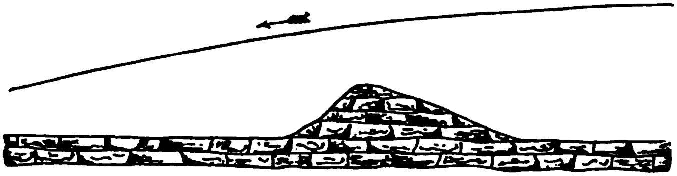


Fig. 213.—Diagram showing the effect of glacial wear on a hill such as is shown in Fig. 212.

Glaciers make scratches, or *striæ* (Fig. 216), on the rock beneath, and under favorable conditions great grooves (Fig. 217) are formed. The striæ are made by the stones carried in the bottom of the ice. The grooves are sometimes made where the bed-rock is softer, or where great bowlders are held firmly in the bottom of the ice, and urged along under great pressure. Such grooves as those shown in Fig. 217 are probably not altogether the work of the ice. The main channel was probably cut by running water, after which the ice passed through the channel, wearing it into its present form. Fine, clayey material in the bottom of the ice polishes the rock below. The polish, the striæ, and the grooves left on the sur-

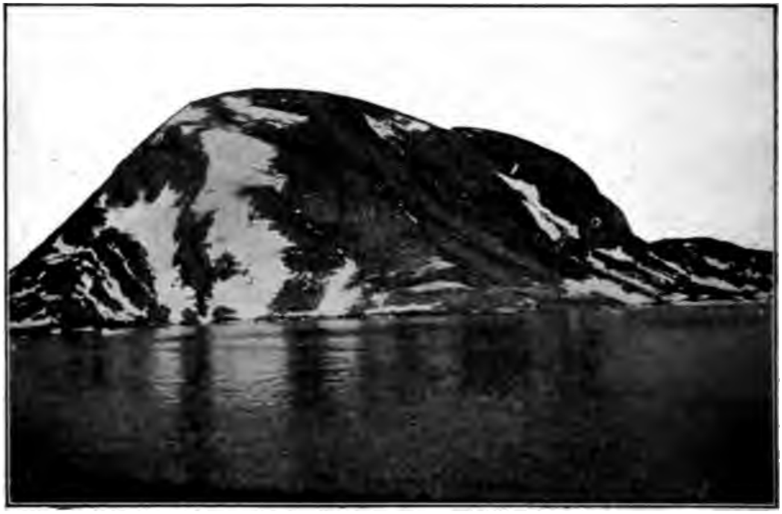


Fig. 214.—A hill smoothed by the glacier ice which overrode it. **Shore of** North Greenland. (Chamberlin.)

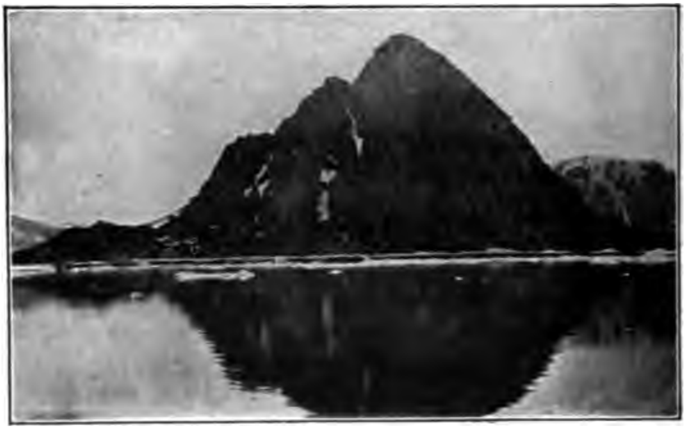


Fig. 215.—A hill near the last not overridden and smoothed by ice. (Chamberlin.)

face of the rock after the ice has melted are among the clearest marks of the former existence of glaciers. In any limited area, the striæ are generally parallel to one another, and show the direction in which the ice moved.

The stones in the bottom of the ice are rubbed against one another, as well as against the bed of the glacier, and are scratched much as the bed-rock is (Figs. 218 and 219). Since the stones in the ice shift their positions from time to time as the ice goes forward, they are frequently striated on two or more sides.

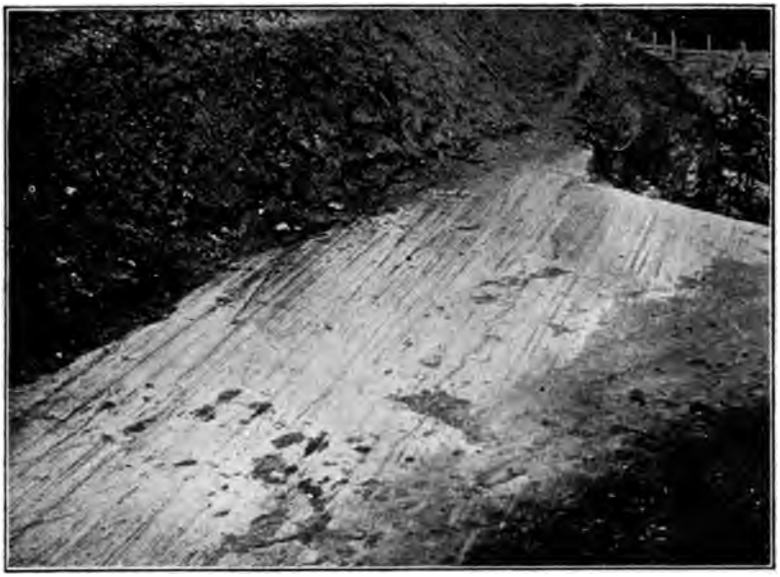


Fig. 216.—Striæ on bed-rock. Kingston, Des Moines County, Iowa.

As the materials carried by the ice rub against one another and against the bed over which they pass, they are worn smaller and smaller. The finest products of the grinding have been called *rock flour.* The materials carried by the ice are therefore of all grades of coarseness, from the finest earth up to huge masses many feet in diameter (Figs. 220 and 221).

How debris is carried. The larger part of the material carried by a glacier is carried in its lower part; but some is carried in the ice above its bottom, and some on the surface.

The material in the base of the ice is readily understood from the way in which it is gathered. The material above the bottom reaches its position in various ways. Some of it falls down from the top through crevasses, but more of it is worn from hills over which the ice has passed, as illustrated by Fig. 223. Under some circumstances, too, ice moves up from the bottom of the glacier (Fig. 224), and carries debris with it.

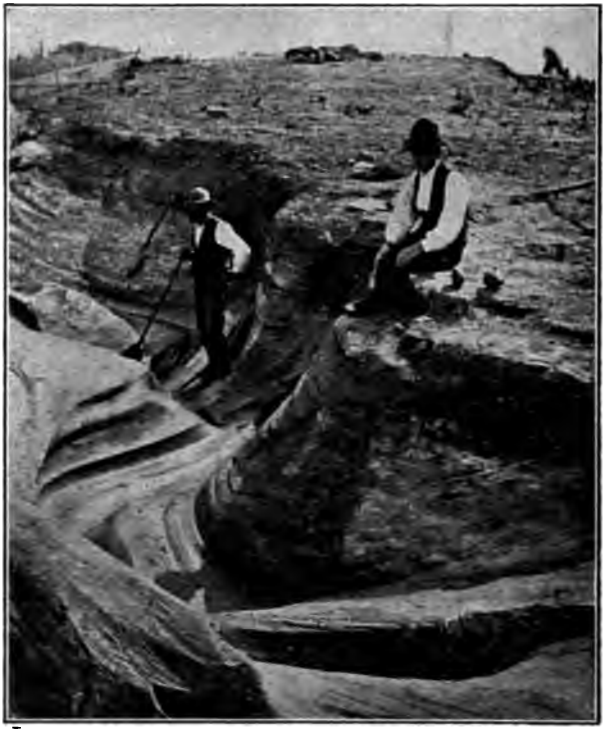


Fig. 217.—Rock grooved by glaciation. The gorge was probably formed by a stream under the ice, and then worn by the ice. Kelley Island, Lake Erie. (U. S. Geol. Surv.)

The material on the surface of a glacier, like that in the ice, reaches its position in more ways than one. Where the slopes above the glacier are steep, rocks may fall or slide down to the surface of the ice. or are brought down by slides of snow (*avalanches*). Some

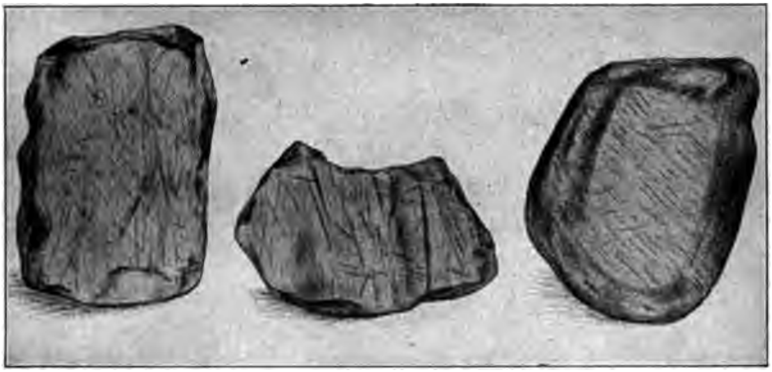


Fig. 218.—Stones striated by glacial wear. (Miss Matz.)

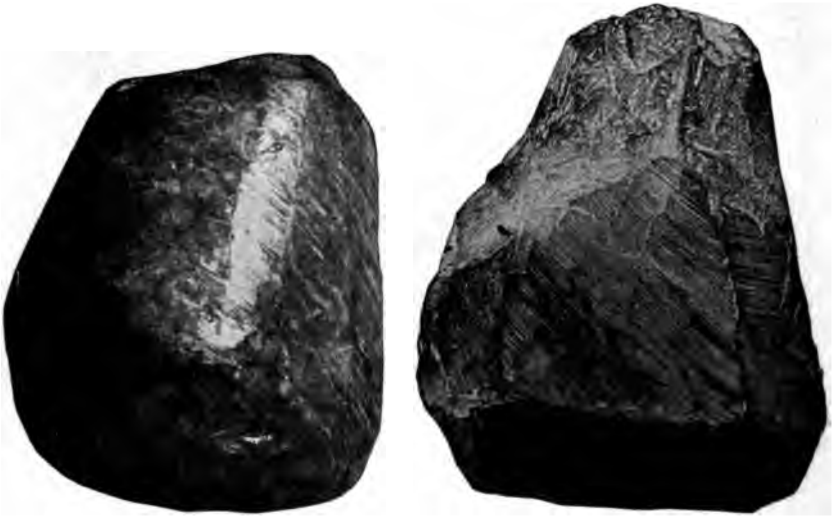


Fig. 219.—Stones in the drift striated and beveled by glacial wear. (U. S. Geol. Surv.)

of the debris on the ice comes up through the ice, as illustrated by Fig. 224.

If the debris which reaches a glacier from the cliffs above lodges along its margin, it makes a *lateral moraine* (p. 171), and if two glaciers bearing lateral moraines unite, as sometimes happens, the two lateral moraines of the sides which come together may form a single *medial moraine* (Fig. 197). But medial and lateral moraines arising in other ways are common on the glaciers of North Greenland.

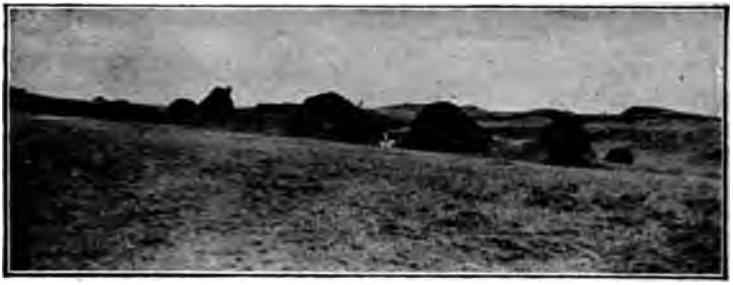


Fig 220.—Bowlders on the terminal moraine of the Okanagan glacier, Wash. (U. S. Geol. Surv.)

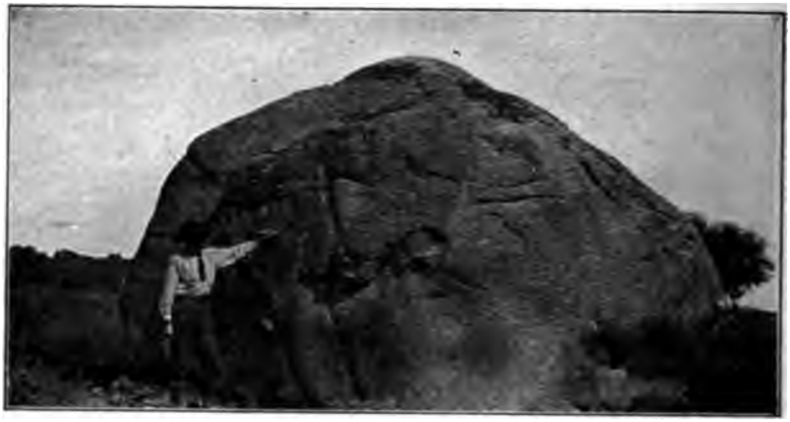


Fig. 221. A large bowlder in northwestern Illinois. (Carman.)

Deposition

Some of the debris which the ice carries in its bottom lodges on the surface beneath while the ice is in motion. That which is deposited at one time may be taken up and carried on again later.

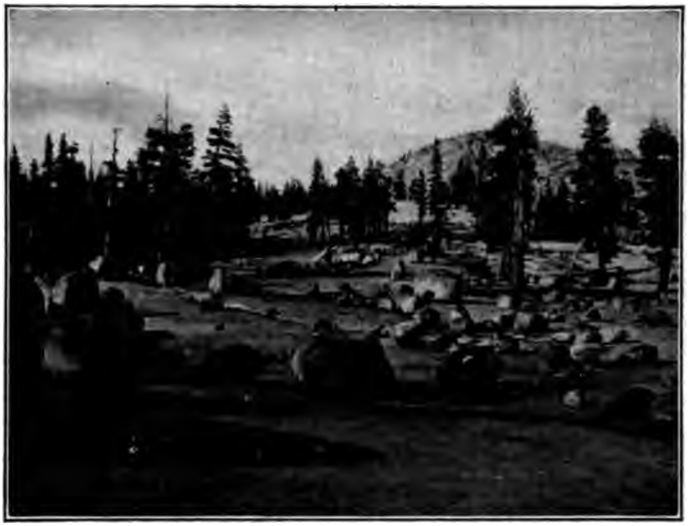


Fig. 222.—Glacial bowlders left on a surface of bare rock, with little other drift. Near Lake Tenaya, California.

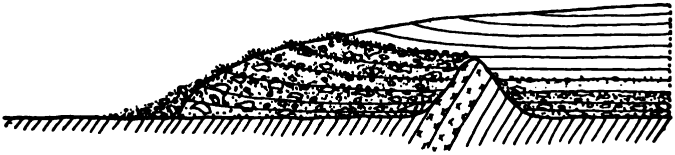


Fig. 223.—Diagram illustrating one way in which a glacier gets material up above its bottom.

In this respect, deposition by glaciers is somewhat like the deposition of streams (p. 128). The material deposited by glaciers is called *glacial drift*.

If the ice at the end of a glacier moves forward two feet a day, the end of the glacier would advance two feet *if none of the ice melted.* If the ice of the glaciers moves forward two feet a day, and if, at the same time, two feet of ice at the end are melted each day, the end of the glacier does not advance, even though the ice keeps moving.

When the end of a valley glacier or the edge of an ice-cap stays in the same place for a long time, a thick body of drift is lodged beneath it (Figs. 225 and 226), for drift is continually brought to this position by the on-coming ice, and left there.

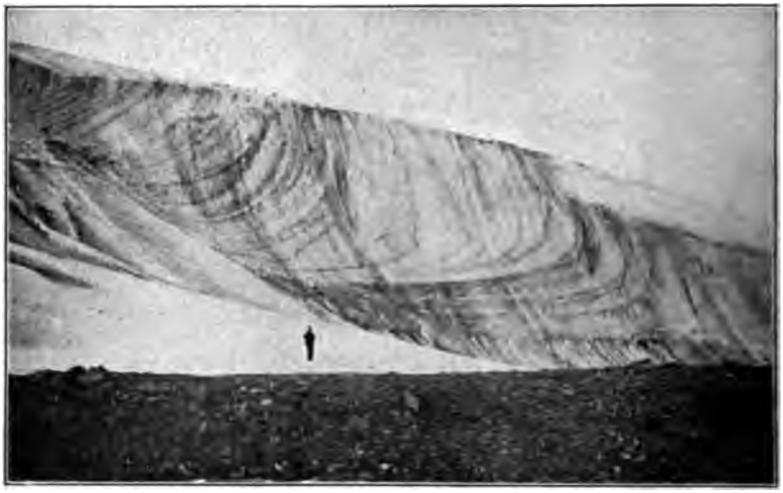


Fig. 224. -End of a North Greenland glacier, showing the upturning of the layers of ice at the end. At one point a few stones are seen on the surface of the ice, where an upturned layer comes to the surface. This structure is common in North Greenland.

The thick body of drift accumulated beneath the end of a valley glacier, or beneath the marginal part of an ice-sheet, is called a *terminal moraine*. The terminal moraine left after the ice melts is not to be confused with the terminal moraine on the glacier. The former is made up very largely of the drift carried in the bottom of the ice and lodged beneath its end, or in the case of an ice-sheet, *beneath its edge.* A terminal moraine formed beneath the ice becomes large only when the end of the glacier remains nearly constant in position for a long time.

When the glacier melts, all the debris which it carried is left on the surface. When the ice is gone, therefore, the whole surface which it covered is likely to be strewn with drift. All the drift deposited by the ice (not that deposited by water which accompanies the ice), which is not in thick belts accumulated at its edge, is *ground moraine*. The area of the ground moraine, therefore, is nearly as great as the area of the glacier itself. It would be just as great except that the ice does not always carry debris at every point in its bottom. When it melts, therefore, there are some areas of bare rock (Fig. 227). In the case of valley glaciers which have melted away, these areas of bare rock are commonly near the heads of the valleys; in the case of ice-sheets, they are most abundant toward the centers of the tracts from which the ice has melted.

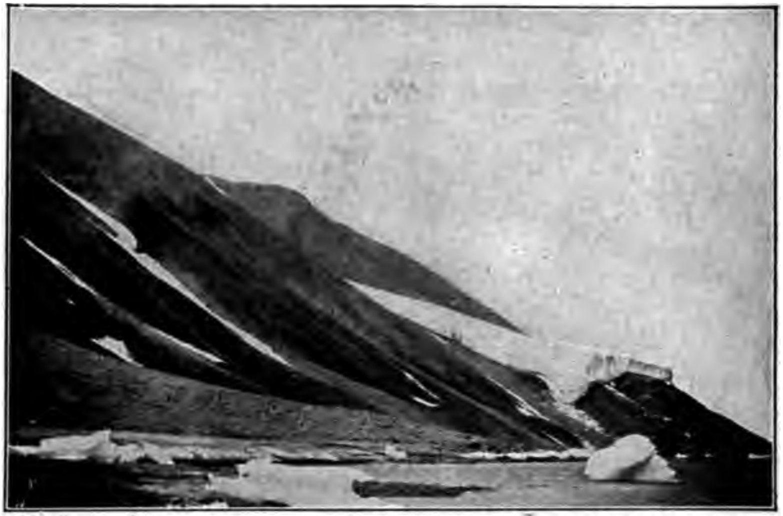


Fig. 225.—Thick accumulation of drift under the end of a glacier. The end has probably been in about the same place for a long time. McCormick Bay, North Greenland.

Lateral moraines exist on valley glaciers (p. 171), but this name is also applied to certain parts of the drift left by a valley

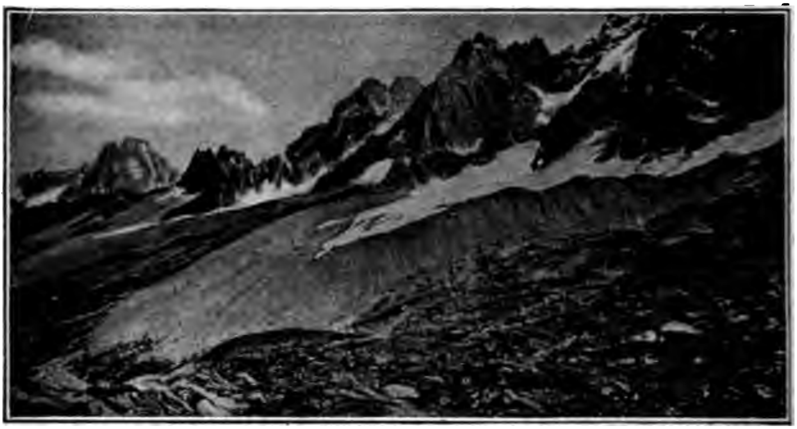


Fig. 226.—The moraines of a small glacier on the slope of Mont Blanc. (Tairraz.)

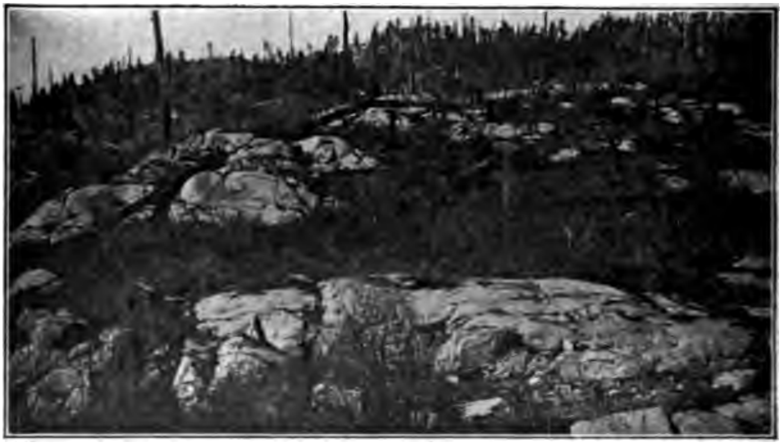


Fig. 227.—Smoothed masses of bare rock over which the ice moved, but on which it left no drift.

glacier after it melts. The lateral moraines which were on a glacier are left in the valley when the ice melts, but they are commonly too small to be conspicuous after the ice is gone. But the lateral moraines which remain after a valley glacier has disappeared are often very large (Figs. 228 and 229). They are often hundreds of feet high, and in a few cases even more than a thousand. The highest lateral moraine known, about 2,000 feet high, is in northern Italy. It was made by a giant glacier which once came down from the Alps. A valley glacier moves from its center toward either side, as well as down its valley, and spreading sidewise from the center, it is constantly shifting debris from the axis of the valley to the edge of the ice on either side. The lateral moraine left after the ice is gone, is therefore of the nature of a *terminal moraine beneath the sides of the ice.* Ice-caps do not develop lateral moraines.

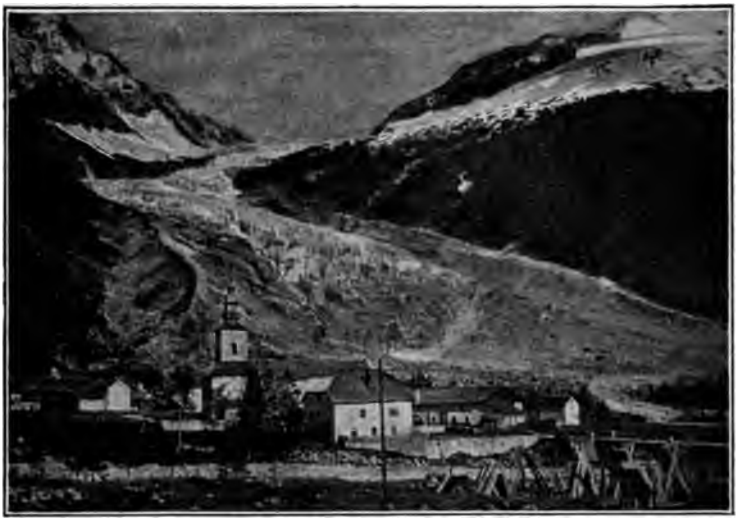


Fig. 228.—The lateral moraines of the Argentière Glacier, Mont Blanc, Switzerland.

Disposition of the drift. Glaciers leave their drift very unevenly distributed over the surface which they once covered. The drift of a terminal moraine is generally much thicker than that of the ground moraine near at hand, while the drift of lateral moraines is sometimes very thick, as already noted. The surface of glacial drift is often marked by hillocks, mounds, and ridges, and by basin-like or trough-like depressions (Figs. 230 and 231). Some of the latter give rise to lakes, ponds, and marshes. The surface of drift *is therefore* very unlike the surface developed by the erosion of

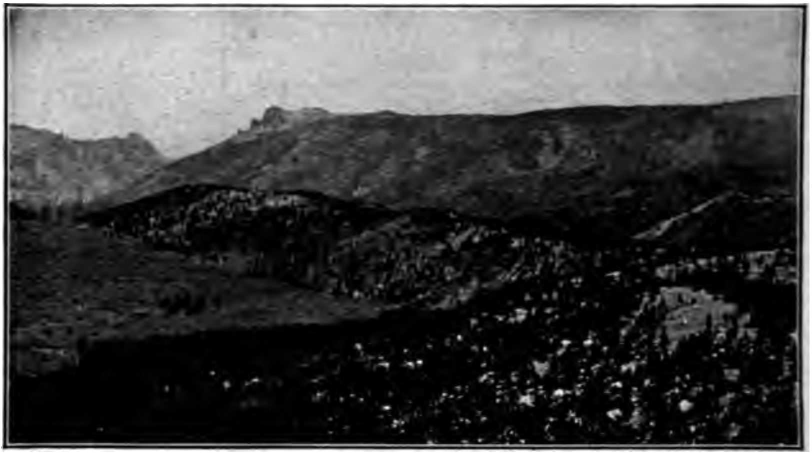


Fig. 229.—A lateral moraine left by a former glacier in the Bighorn Mountains of Wyoming. (Blackwelder.)

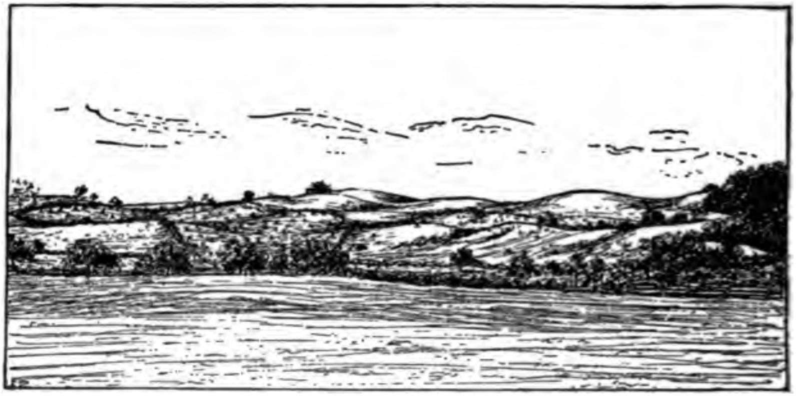
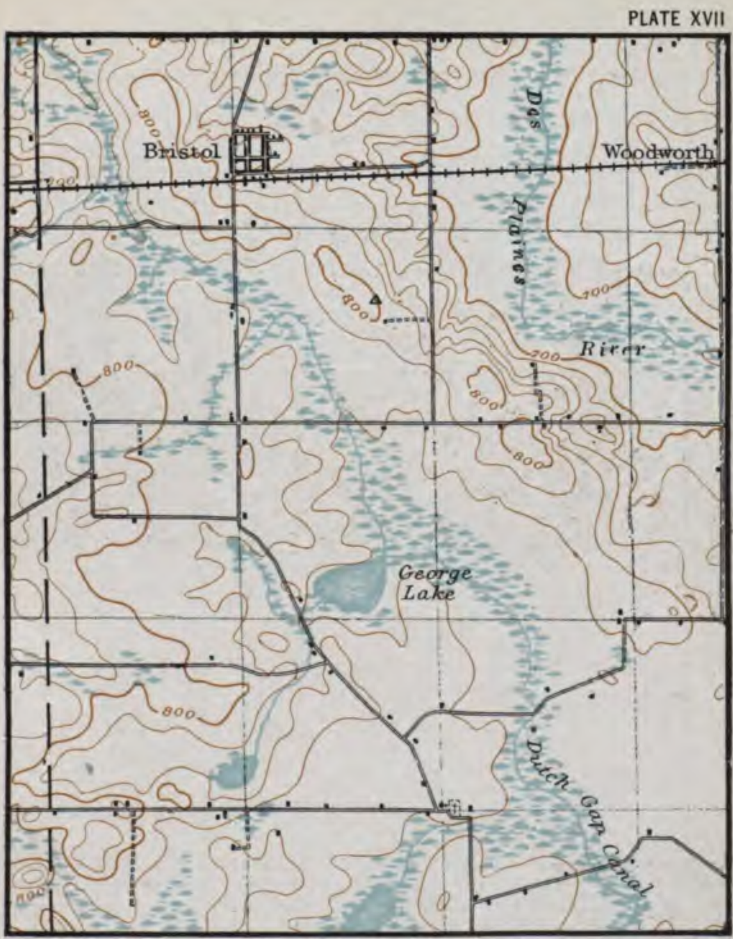
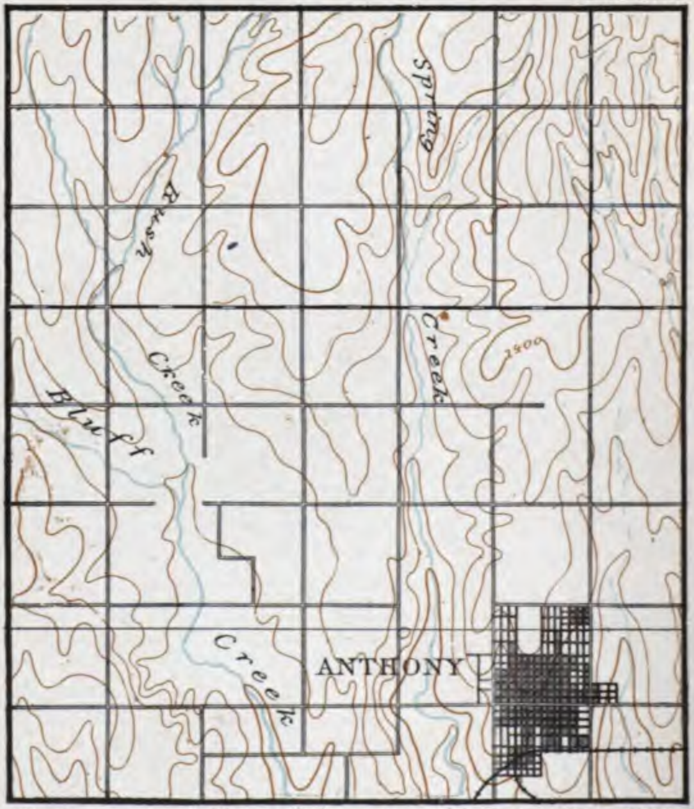


Fig. 230.—Sketch of drift (terminal moraine) topography near Hackettstown, N. J. (N. J. Geol. Surv.)



Characteristic surface of a glaciated plain, showing marshes, ponds, and lakes. Southern Wisconsin. Scale about 1 mile per inch. (Silver Lake, Wis., Sheet, U. S. Geol. Surv.)



The topography of this map is in contrast with that of Plate XVII. Here the elevations and depressions have definite relations to the drainage. Scale about 2 miles per inch. (Anthony, Kan., Sheet. U. S. Geol. Surv.)

running water, for in the latter the depressions have outlets, and the hills and ridges stand in a very definite relation to the valleys (compare Pls. XVII. and XVIII). In valleys, terminal moraines

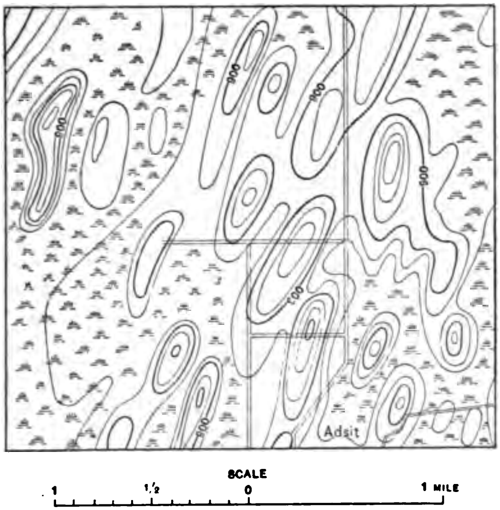


Fig. 231.—One phase of ground moraine topography; elongated hills of drift of the type shown here are called *drumlins;* southeastern Wisconsin. (U. S. Geol. Surv.)

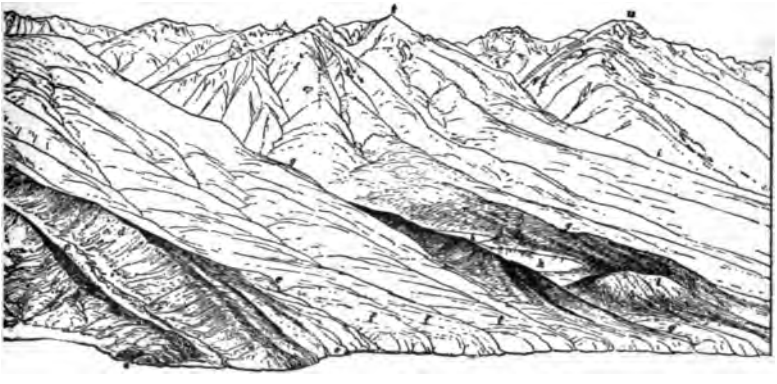


Fig. 232.—Sketch of a part of the Sawatch Mountains, Colorado, showing moraines (*c*, *d*, *g*, and *i*) and lakes (*h*, *h*) in the glaciated valley.

often make dams, and so pond the waters of the streams above, making lakes (Fig. 232). The basins of many of the lakes of glaciated mountain valleys were made in this way.

Fluvio-glacial Deposits

Water flows in abundance from all glaciers in the summer, and from many glaciers all the time. Stream-work, therefore, accompanies glaciation in all cases, and some of the drift left by ice is modified by water afterward.

The streams which flow from glaciers carry much sediment. At the outset, this sediment consists of both coarse and fine material, but the coarse materials are generally dropped before the water has flowed far. The sand is carried farther than the gravel, and the silt farther than the sand. Many streams flowing from glaciers carry so much silt in suspension that the water is turbid, and if the silt is whitish, as it often is, the streams are said to be "milky."

By the deposition of this river-borne material, the valleys below glaciers are often aggraded. The materials deposited by the glacial streams are stratified, and so are in contrast with the drift left by the ice itself.

The gravel, sand, etc., deposited by a stream in the valley below a glacier is a *valley train*. It is simply an alluvial plain developed by a stream flowing from a glacier, and carrying much gravel, sand, etc. Valley trains are best developed just outside terminal moraines (Fig. 233).

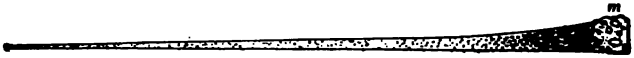


Fig. 233. —Diagram to illustrate the profile of a valley train, and its relations to the terminal moraine (*m*) in which it heads.

In the case of an ice-cap, the water which issues from the ice often fails to find a valley. Each issuing stream then tends to develop an alluvial fan. By growth, these fans may unite, making an alluvial plain, very much like a compound alluvial fan (p. 127). Such a plain, composed of material washed out from the ice, is an *outwash plain* (Fig. 234). Like valley trains, outwash plains are

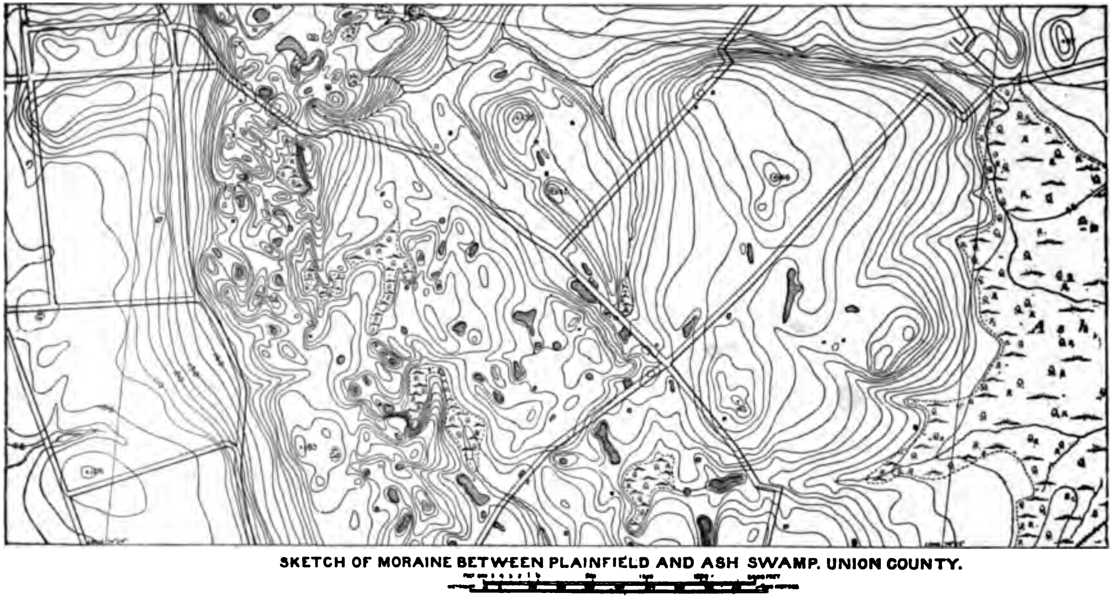

SKETCH OF MORAINE BETWEEN PLAINFIELD AND ASH SWAMP. UNION COUNTY.

Fig. 234.—A map of a small area of drift in New Jersey. The central belt of rough topography is *terminal moraine*. The area at the extreme left is drift (gravel, and sand) washed out beyond the edge of the ice by streams, making an *outwash plain*.

best developed just outside the terminal moraines of ice-sheets, and their materials are stratified.

Lakes may exist at the ends or edges of glaciers, and drainage from the ice may build deltas in them, just as other streams build deltas in the standing water into which they flow.

Streams sometimes exist in the ice (Fig. 235) and under it. The streams under the ice (sub-glacial streams) sometimes deposit gravel and sand in their channels, building them up so that when the ice melts the old bed of the stream appears as a low but narrow ridge. Such a ridge is called an *esker* (Fig. 236). The channels under the ice sometimes have the effect of tubes through which the water is forced with considerable velocity. As it issues from beneath the ice, its velocity is checked, and it sometimes makes extensive deposits of gravel and sand at the margin of the ice. These deposits are stratified, but the stratification is often irregular. They are often left against the edge of the ice, and when the edge melts they appear as mounds and ridges, called *kames* (Fig. 237).

The streams on the ice rarely make deposits of consequence.

As the ice melts away, the waters produced by the melting, flow over the surface of the drift which the ice had already deposited, and modify its surface to some extent by eroding in some places and depositing in others. As a result of all these phases of water-work, much of the drift is stratified.

Icebergs

Icebergs (Fig. 200) are masses of ice broken off from the ends of glaciers which move down into the sea. Bergs derived from Greenland float as far south as Newfoundland in considerable numbers. They are seen occasionally still farther south, but by the time they have moved so far from their source they are usually small. The bergs from Greenland rarely project 200 feet out of water, and most of them not more than 100 feet, but they are sometimes a mile or more across. In the South Polar regions the bergs are still larger. When river or lake ice floats, about nine-tenths of it is below the water and one-tenth above. Glacier ice is less heavy, unless loaded down with rock debris, for snow-ice is *not so compact* as the ice formed on rivers and lakes. Making

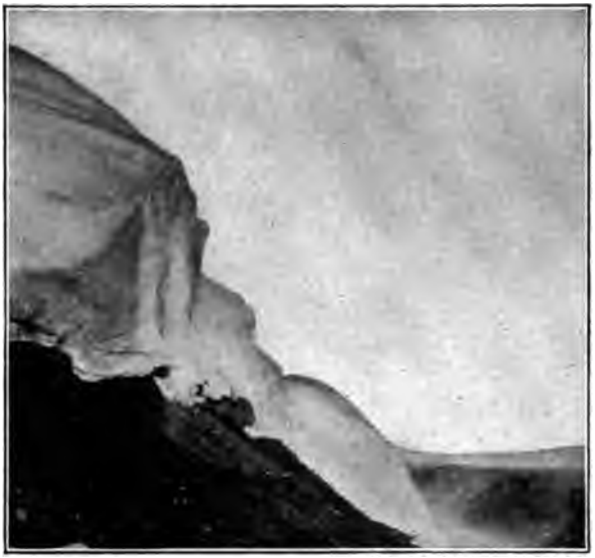


Fig. 235.—Spouting stream. Glacier, south side of Olriks Bay, North Greenland, 1895.

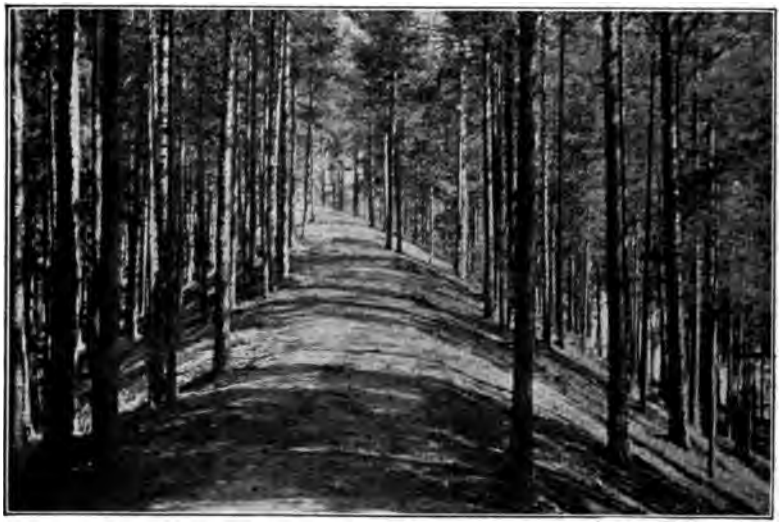


Fig. 236.—An esker in Scandinavia.

allowance for this difference, a berg 200 feet out of water may be 1,000 to 1,500 feet thick.

As icebergs sail away from land, they carry some of the debris which was in the bottom of the glacier. As the floating ice melts, the debris which it carried falls to the bottom. The northern icebergs do not appear to carry much debris far. Most of them lose all their rock material before they have floated 100 miles. The common notion that the banks of Newfoundland were made by berg deposits probably has no foundation in fact.

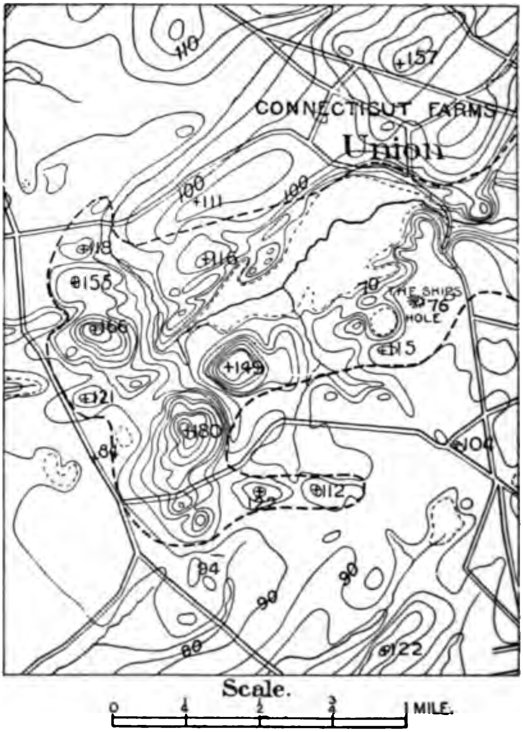


Fig. 237.—A group of kames near Connecticut Farms, N. J. (N. J. Geol. Surv.)

The courses of icebergs are determined partly by winds, and *partly by currents* in the ocean. Those of the North Atlantic occasionally reach the track of transatlantic commerce. Since they are sometimes surrounded by fog, they may be a menace to navigation.

ANCIENT GLACIERS AND ICE-SHEETS

There have been times in the earth's history when glaciers were much more extensive than now. The latest of these periods is known as *the glacial period*, when mountain glaciers were very much more numerous and very much larger than now. In our own country glaciers existed even in the mountains of New Mexico, Arizona, and Nevada. The amount of ice in the glaciers of Utah or Colorado was then far greater than all that now exists in the United States south of Alaska. At the same time, a great area east of the Cordilleran mountain system, some 4,000,000 square miles in extent (Fig. 238), and lying partly in Canada and partly in the United States, was covered with an ice-sheet, or *continental glacier.*

The ice-sheet of North America seems to have originated in two principal centers, one on either side of Hudson Bay. The beginning of each was doubtless a great snow-field. At first these snow-and-ice fields grew by the addition of snow, and later by the spread of the ice to which the snow gave rise. The two ice-sheets finally became one by growing together (Fig. 238). This great continental glacier did not originate in mountains, but on high plains.

When it was largest, this ice-sheet covered all of New England, the northern parts of New Jersey and Pennsylvania, and much of Ohio and Indiana. Its edge crossed the Ohio River where Cincinnati now stands, and advanced a few miles into Kentucky. Farther west it reached almost to the southern end of Illinois. Its edge crossed the Mississippi near St. Louis, and followed, in a general way, the course of the Missouri River to western Montana. Most of the continent north of this line was covered with snow and ice, but there was an area of 8,000 to 10,000 square miles, mainly in southwestern Wisconsin, which the ice did not cover. This is known as the *driftless area*, because there is no drift in it. There was a great body of ice also in the Cordilleran mountains (Fig. 238), but it always remained somewhat distinct from that which spread from the other centers.

There was extensive glaciation in Europe at about the same time as in North America. The glaciers of the Alps were then many times as large as those of the present time. On the south they extended quite beyond the mountain valleys, and spread themselves out on the plains of northern Italy where they left their moraines. Similar conditions existed in the other mountains of

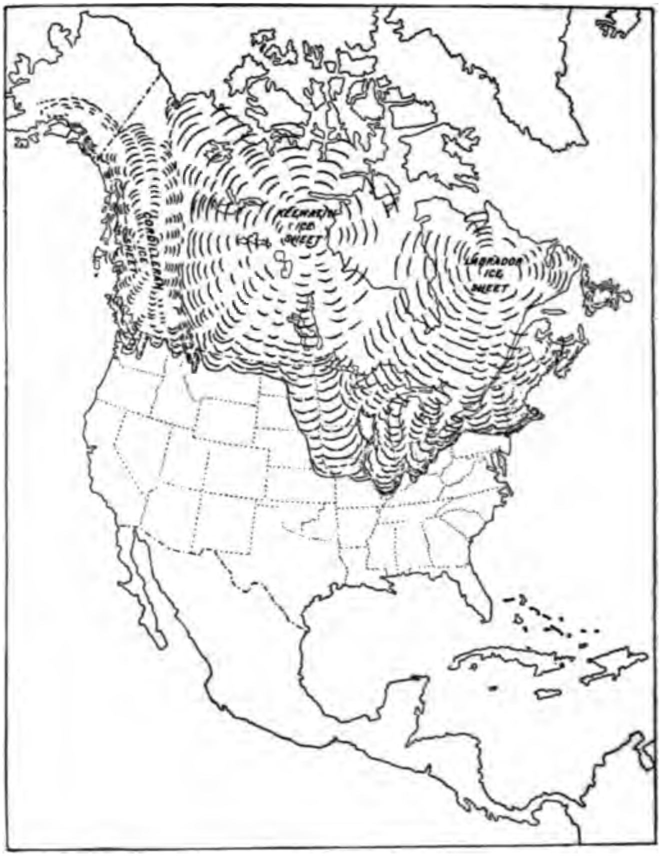


Fig. 238.—Sketch-map showing the area in North America covered by ice at the maximum stage of glaciation. (U. S. Geol. Surv.)

Europe where glaciers now exist, and in some where glaciers are not now present.

In northern Europe, as in the northern part of North America, there was an extensive ice-sheet, but its area was only about half that of the ice-sheet of North America. The center from which the ice of Europe spread was the high mountains of Scandinavia, with perhaps other centers in the highlands of Scotland, and in the Ural Mountains. At the time of its greatest extension, this ice-sheet covered all of Great Britain, except its southernmost part, all of northern Germany, and much of Russia (Fig. 239).

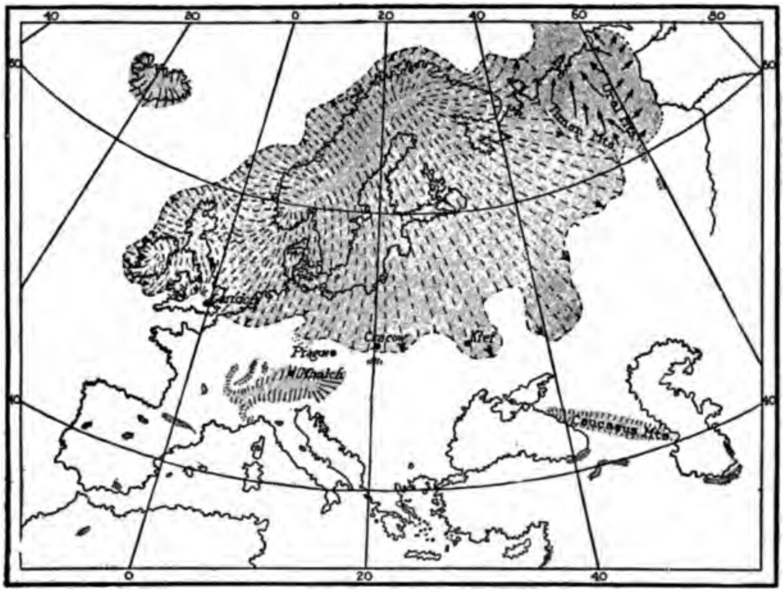


Fig. 239—Sketch-map showing the area of Europe covered by the continental glacier at the time of its maximum development. (Jas. Geikie.)

Great ice-sheets are not known to have developed in other continents during the glacial period, but their mountain glaciers were very large.

The history of the continental glaciers was complex, both in Europe and North America. In North America v was somewhat as follows: After the growth of the first great ice-sheet. it shrank to small size, or disappeared altogether. Then followed a relatively warm period, when plants and animals lived in the region abandoned by the ice. Another continental ice-sheet then developed, spreading over the region from which the first had melted, and extending still farther south. As it advanced, the second ice-sheet occasionally buried the soil on the top of the drift left by the ice of the first epoch. Such soils, sometimes with the remains of the plants which grew in them, are one of the means by which it is known that there was more than one ice-sheet. A third, fourth, and fifth ice-sheet, each somewhat smaller than its predecessor, developed and disappeared. In other words, there were at least five epochs when ice-sheets were extensive, separated by epochs when the ice was greatly diminished, or when it disappeared altogether. The ice-sheets of Europe had a similar history.

Cause of the Glacial Epochs

The development of the great ice-sheets was doubtless due to a change in climate, and especially to a reduction of temperature. The cause of the cold is not certainly known, though many explanations have been suggested. One was that the northern lands were raised to great heights. Another was based on changes in the shape of the earth's orbit, and on changes in the direction of the earth's axis. But the hypothesis which now seems most likely to prove to be true is, that the change of climate was due to some change in the atmosphere. An increase in the amount of carbonic-acid gas and water vapor would make the climate warmer, while a decrease in these elements would make it colder. Good reasons have been suggested for variations in the amounts of these substances in the air, and also for the heavy precipitation, which is as necessary as low temperature for extensive glaciation, in the regions where the ice-sheets existed.

CHANGES PRODUCED BY THE CONTINENTAL GLACIERS

The ice-sheets of North America produced many changes in the surface which they covered. Some of these changes were brought about by the erosion of the ice, and some by the deposition of the drift. A brief statement of these changes will serve to review the work of ice-sheets. It is important to remember, in this connection that the continental glaciers of North America developed on the surface of a rather high plain, whose topography had been shaped, in large measure, by river erosion.

Changes Produced by Erosion

1. *On Elevations.* The ice was thick enough to cover the hills and low mountains of the area shown in Fig. 238. As it passed over them, it wore off their tops, and so tended to make the surface smoother. Very small elevations were often worn away altogether, but the ice had not strength enough to remove large hills or mountains. It only changed their shapes a little, as shown by Figs. 214 and 215.

2. *In valleys.* The ice deepened the valleys through which it moved, and in many cases it deepened them more than it lowered the hills. Where this was the case, the *relief* of the surface was increased; but even where this was true, the *roughness* of the surface was often diminished, for roughness depends on the frequency with which elevations and depressions, such as hills and valleys, succeed one another, and on the steepness of their slopes, quite as much as on the amount of relief (compare Figs. 240 and 241).

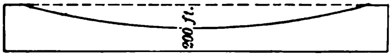


Fig. 240.

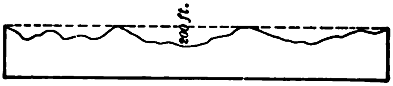


Fig. 241.

Figs. 240 and 241.—These two figures show surfaces with the same amount of relief, but the one, 241, is much rougher than the other.

3. *Rock basins.* Another effect of ice erosion was to gouge out hollows, or basins, in rock (Fig. 211), where the underlying rock was relatively weak. Such basins are less common in the area of the continental ice-sheet than in mountain valleys affected by glaciers.

Changes Produced by the Deposition of the Drift

Sooner or later the ice deposited all of the material which it gathered by erosion. Had the drift been equally thick everywhere, its effect would have been to raise the surface without altering its topography; but the drift is distributed with great inequality, and therefore changes the surface greatly.

Effect of drift on topography. The drift sometimes increases the relief of the surface (Fig. 242), but oftener decreases it (Fig. 243). On the other hand, the drift was sometimes left in such a way as to make the surface rougher than the surface of the rock below, even where the relief was decreased (Fig. 244).

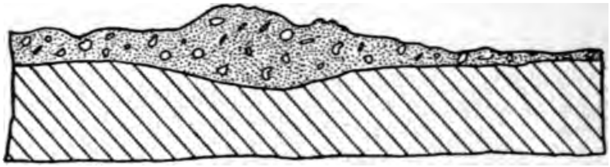


Fig. 242.—Diagram to show how drift may be so disposed as to increase the relief of the surface. This should be compared with the two following figures.

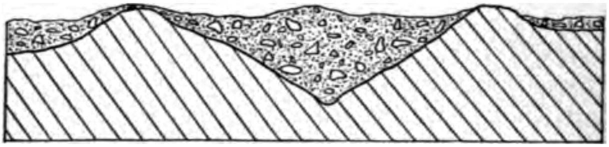


Fig. 243.—Diagram to illustrate how drift may decrease the relief of the surface.

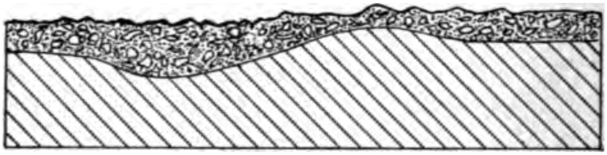


Fig. 244.—Drift so disposed as to make the surface rougher, though the relief of the surface is decreased.

Both the erosion of the ice and the deposition of its drift produced topographic features very unlike those made by streams.

Effect of drift deposits on drainage. *a. Lakes.* The drift filled valleys at some points, but not at others. Where a valley is filled at one point, water is likely to accumulate above the filling, as above a dam, making a lake. Where a valley was filled in two places, as sometimes happened, the unfilled part between became a basin fit for a lake. Devil's Lake, in Wisconsin, is an example (Fig. 245). The number of lake basins which arose by the filling of river valleys in one or more places by drift is very large. The remarkable Finger Lakes of New York are examples. Rock basins were often made deeper by the deposition of drift about their rims.

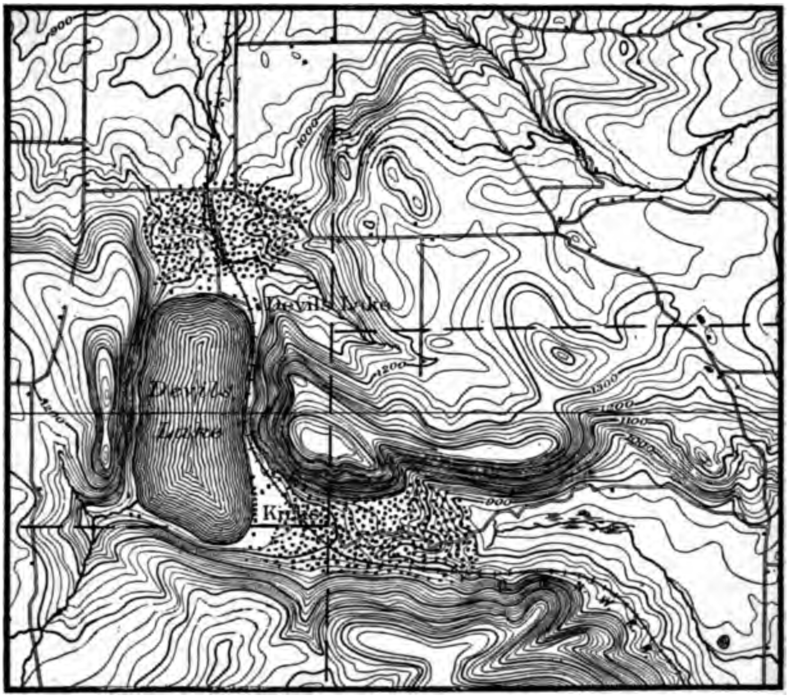


Fig. 245.—Sketch showing a lake in a former river valley, held in by drift dams. The dotted areas are terminal moraines.

The ice-sheets gave rise to lakes and ponds in other ways also. Many of them are in hollows in the surface of the drift. Nearly all the numerous lakes of North America are in the area which was covered by the ice-sheet or by mountain glaciers. They are most numerous in the area covered by the ice of the last glacial epoch, as in North Dakota, Minnesota, Wisconsin, Michigan, New York, and New England.

Some lakes produced by the ice had but a short life. Such was the history of those which came into existence along the margin of the ice-sheets, where the ice itself formed one border of the lake. The melting of the ice brought such lakes to an end.

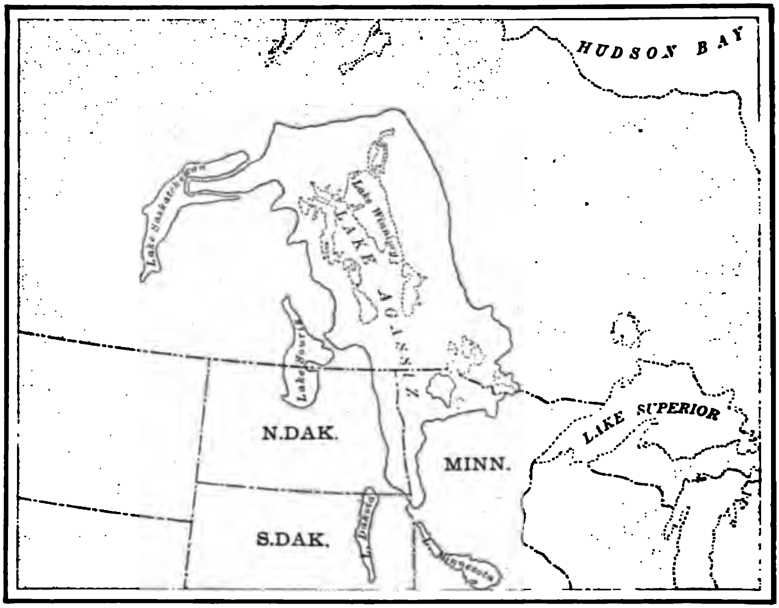


Fig. 246.—Map of the extinct Lake Agassiz, and other glacial lakes. Lake Winnipeg occupies a part of the basin of Lake Agassiz. (U. S. Geol. Surv.)

One of the largest of the marginal lakes (Lake Agassiz) lay in the valley of the Red River of the North (Fig. 246). When this lake was largest, its length was 700 miles, its greatest width about 250 miles, and it covered an area of about 110,000 square miles, an area greater than that of all the Great Lakes. The water, however, was shallow. It came into existence when the edge of the retreating ice lay north of the lake, and stopped drainage in that direction.

The water rose in the basin until it overflowed to the south, finally reaching the Misissippi River. When the ice at the north melted back far enough, a new and lower outlet was opened to Hudson Bay, and the lake was drained. Lake Winnipeg and several smaller lakes may be looked upon as remnants of this great lake, for they occupy the deepest parts of the old basin.

The borders of the former lake are marked by beaches and deltas. The silt-covered bottom of the lake is one of the most important wheat-producing areas in the United States.

The Great Lakes of the present day were larger than now after the ice had retreated north of their basins, but while it still covered the lower part of the St. Lawrence Valley. A part of their history, dating from the time when the last ice-sheet was waning, is suggested by Figs. 247 to 250. These lakes did not exist, so far as now known, before the glacial period, but rivers probably flowed in the direction of their longer diameters. Lake basins seem to have been developed from these river valleys as a result of (1) the deepening of the valleys by ice erosion, (2) the building up of the rims of the basins by the deposition of drift, and (3) perhaps the down-warping of the sites of the basins.

Marshes also abound (Pl. XVII) within the glaciated area. In some cases they represent the beds of former lakes and ponds, while in others they are in basins too shallow to hold bodies of water deep enough to prevent the growth of plants.

b. Rivers. The disposition of the drift also deranged the rivers. After the ice melted, the surface drainage followed the lowest lines open to it; but these lines did not always correspond with the former valleys, for some of them had been filled, and most of them were blocked up in some places. After the ice melted, therefore, the surface waters followed former valleys in some cases, and flowed across areas where there had been no valleys in others. In choosing their new courses, the streams sometimes ran down steep slopes or fell over cliffs. Thus arose rapids and falls, which, on the whole, are rather common in the glaciated area.

Lakes, as well as rapids and falls, are marks of topographic youth. Rivers are, on the whole, hostile to lakes, for the inflowing streams bring in sediment which tends to fill the basins, and o

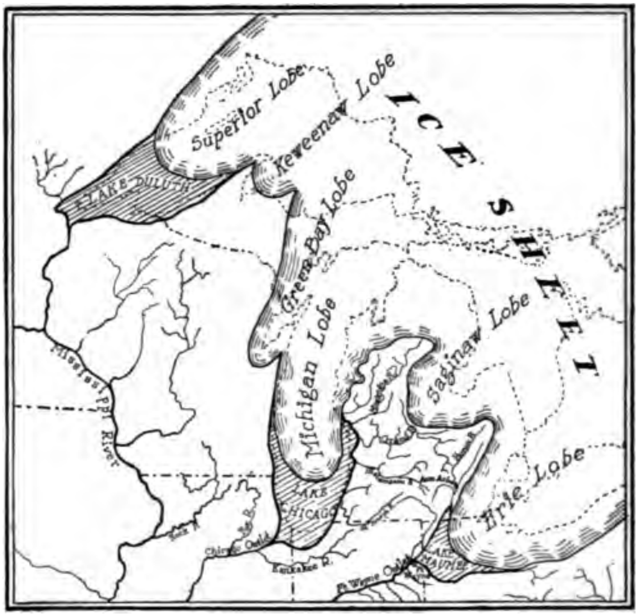


Fig. 247.—The beginning of the Great Lakes. The ice still occupied the **larger** parts of the present lake basins. (U. S. Geol. Surv.)

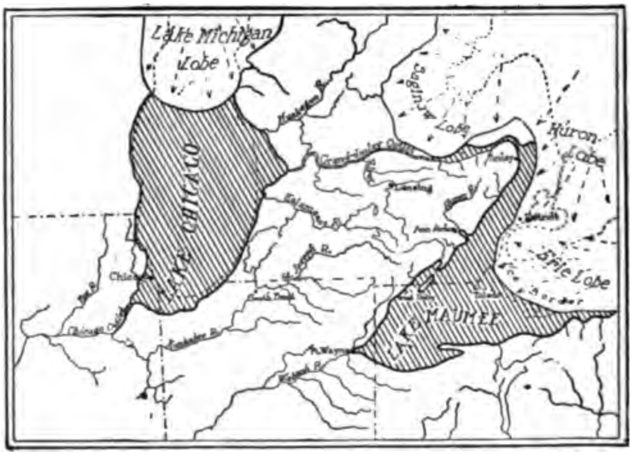


Fig. 248.—A later stage in the development of Lakes Chicago **and Maumee. The ice has retreated, and the outlet of Lake Maumee has been shifted (U. S. Geol. Surv.)**

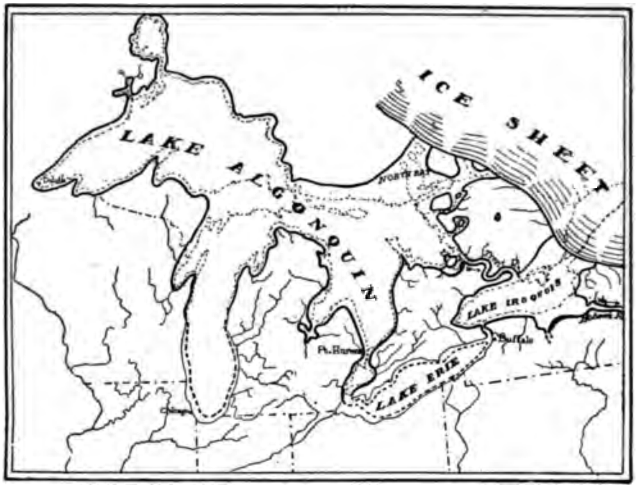


Fig. 249.—The Great Lakes at the Algonquin-Iroquois stage. The outlet to the sea is by way of the Mohawk Valley. (Taylor.)

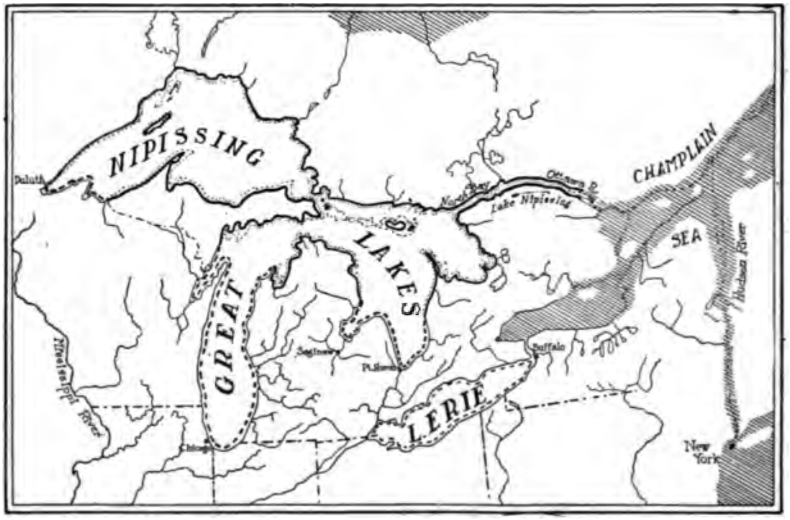


Fig. 250.—A still later stage of the Great Lakes. The sea is thought to have covered the area shaded by lines at the east. (Taylor.)

flowing streams cut down their outlets. Many small lakes have already become extinct by these processes, and many others have been made smaller. The fact that so many falls, rapids, and lakes still remain within the glaciated area shows that the time since the melting of the last ice-sheet has not been long enough for these features to be destroyed.

Lakes, ponds, marshes, falls, rapids, etc., are much more abundant in the area of the last ice-sheet than in the area of drift outside of the last ice-sheet. This is largely because the older drift, where now exposed, has been subject to rain and river erosion long enough for most of its lakes to be destroyed. The oldest drift is believed to be many times (probably as many as 25) as old as the youngest.

Stratified drift. Valley trains (p. 194), outwash plains (p. 194), deltas (p. 196), etc., were developed by the continental glaciers, but only those of the last ice-sheet are well preserved, the older ones having been destroyed by erosion. Some of the valley trains are long, and in some the deposits are very deep. Thus the Rock River, in southern Wisconsin, filled its valley with gravel and sand to a depth of 300 to 400 feet just outside the terminal moraine of the last glacial epoch. The Columbia River, swollen by the waters from the melting ice, filled its valley, locally, to the depth of 700 feet, with sediment washed out from the ice.

Since the ice melted, most of the valley trains have been partially carried away, and the remnants of the old plains of aggradation are now terraces (Fig. 170).

Effects of Glaciation on Human Affairs

The changes produced by glaciation have had much influence on the industries of the region which the ice covered. In the United States glaciation increased the amount of mantle rock. This increase is helpful where slopes are rather steep. This is seen by comparison with driftless regions, where the soil is often very thin or absent on the slopes, and where much of the land cannot be cultivated for this reason. Abundant soil is much more likely to be found on similar slopes in the glaciated area. Again, the general effect of glaciation was to reduce slopes, and it therefore tended to make the areas too steep to be cultivated smaller.

The quality of the soil was improved in many places by glaciation, but this was not true everywhere. It is worth noting that most of the wheat and hay grown in the United States east of the Rocky Mountains is within the area which was glaciated. This is, however, not altogether because of the drift, but partly because of the climate.

On the whole, the ice left the surface less rough than it found it. This made it easier to build roads, and so has helped travel and transportation. Locally, however, the surface was made rougher, with disadvantageous results.

The falls, rapids, and lakes which resulted from glaciation have increased the water-power, and the lakes, ponds, and marshes tend to make the streams flow more steadily through the year, by holding back some of the water of wet times, and letting it flow out in times of drought. The flow of streams from lakes is much steadier than the flow of streams which have no such reservoirs to draw upon. The drift is, on the whole, thicker than the mantle rock of other regions, and therefore is able to hold more of the rain which falls in wet weather. This water it yields up slowly, and so makes the supply of ground-water to streams more steady than it would be otherwise.

Much of the drift clay (rock-flour) is used for the manufacture of brick, tile, etc., and the gravel of the drift is used for road-making, and in the manufacture of various sorts of cements.

The results of glaciation were not always helpful to man. Thus, in some places the quality of the soil was injured, for the drift of some places is stony, and great labor is necessary to put it in workable condition. In some places, too, it is too sandy or gravelly to make good soil, and in other places its surface is too rough.

On the whole, it seems probable that the glaciated area of the United States was benefited by the work of the ice.

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CHAPTER VI

LAKES AND SHORES

General Facts Concerning Lakes

Definition. A lake is an inland body of standing water larger than a pool or a pond; but the term is also sometimes applied to the widened parts of rivers (Fig. 171), and to some bodies of water which lie along coasts, even when they are in direct connection with the sea (Fig. 251).

Most lakes are fresh, but a few, like Great Salt Lake and the Dead Sea, are much more salty than the sea itself.

Distribution of Lakes

1. *In latitude.* Lakes occur in most latitudes, but they are more abundant in high latitudes than in low, because the former have been more extensively glaciated than the latter.

2. *In mountains.* Lakes are abundant in some mountain regions, especially in those which have been glaciated in recent times.

3. *Along rivers.* Lakes occur along some rivers. Outside of glaciated regions, they are common only along streams which have low gradients and wide flats, where the origin of the lakes is clearly connected with the changing of the river channel (Pls. VI and VII).

4. *Along coasts.* Lakes are rather common along coasts (Fig. 1, Pl. XIX, and Fig. 251), though many coasts are without them. Coastal lakes stand in no apparent relation to latitude, and their levels are nearly or quite the same as that of the sea.

5. *On coastal plains.* Lakes are found on low lands near the sea in some places, as in Florida, where lakes are as abundant as in the glaciated parts of the United States (Fig. 2, Pl. XIX).

6. *On plateaus.* Lakes occur on some plateaus even where there has been no glaciation. Examples are found in the great lakes of central and southern Africa, and there are numerous shallow lakes on the Great Plains (plateaus) of the United States, even where the climate is dry.

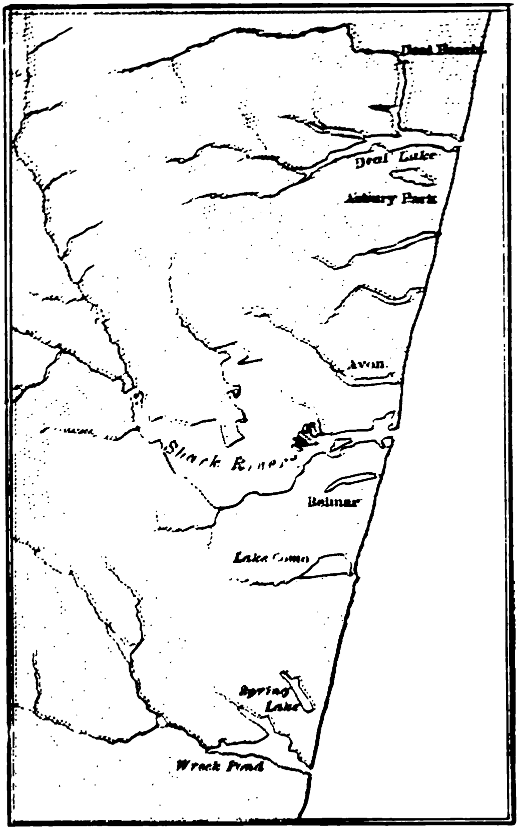


Fig. 251. Lakes on the coast of New Jersey. The expanded part of Shark River is virtually a lake.

7. *Other situations.* Lakes occur in a few other situations, as in the tops of some volcanic mountains, and in mountain valleys where landslides or lava flows have made temporary dams.

PLATE XIX

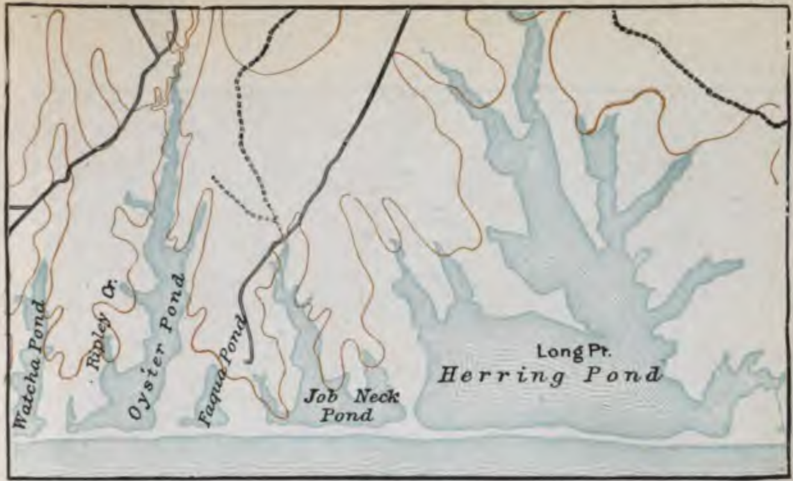


FIG. 1.—Coastal lakes formed by the blocking of the ends of drowned valleys. Scale about 1 mile per inch. (Marthas Vineyard, Mass., Sheet, U. S. Geol. Surv.)

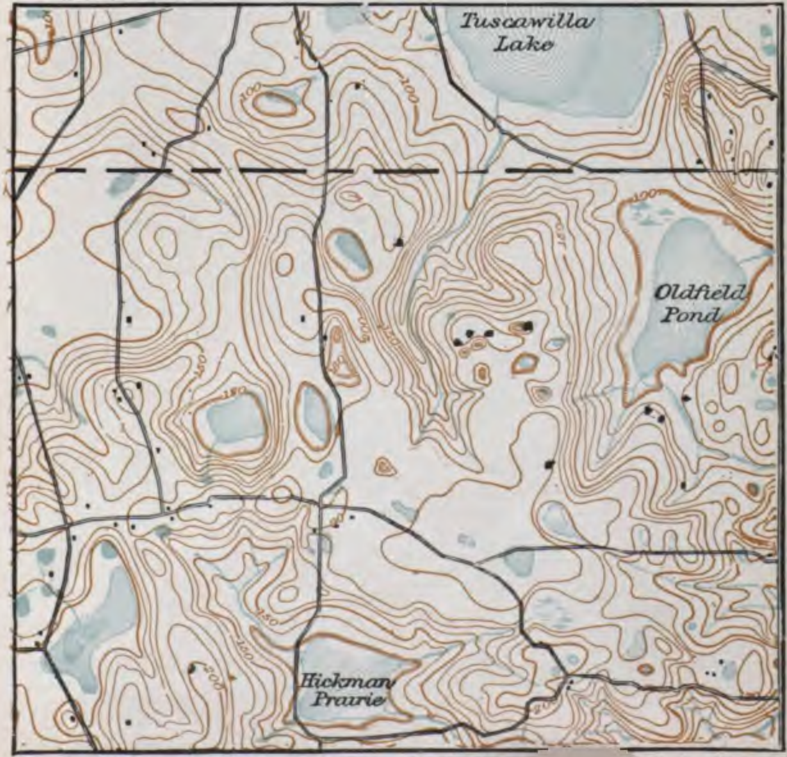
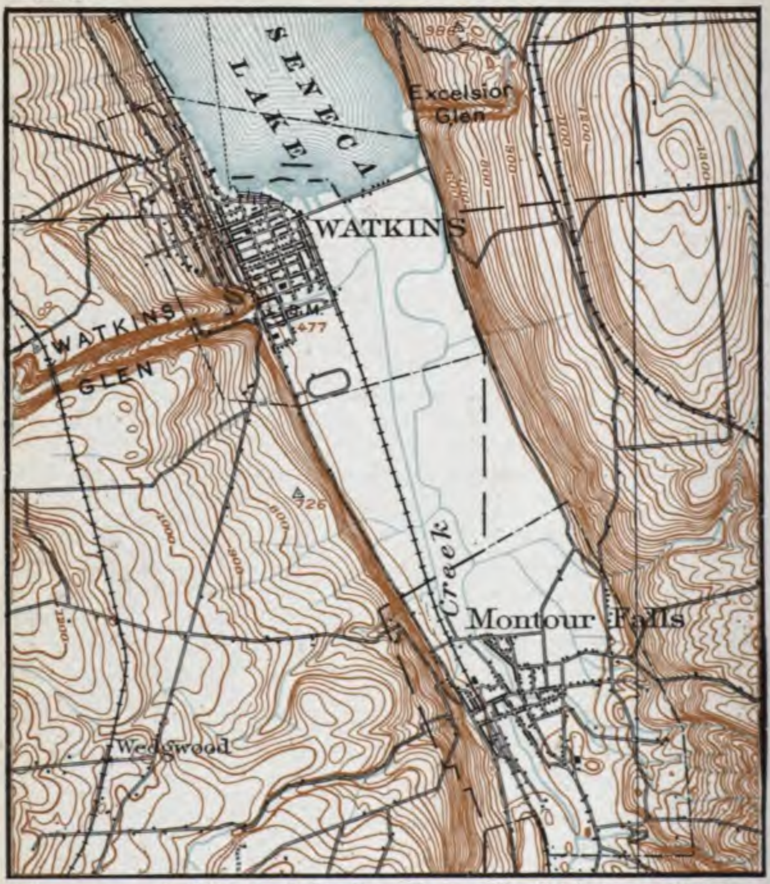


FIG. 2.—A group of lakes on the Atlantic Coas [illegible] cale about 1 mile per inch. (Williston, Fla., Sheet, U [illegible] .)

PLATE XX



The upper end of Seneca Lake, New York. The flat between Montour Falls and Watkins is a delta which has been built out into the lake by the in-flowing creek. Scale about 1 mile per inch. (Watkins, N. Y., Sheet. U. S. Geol. Surv

Area, Topographic Position, Depth, etc.

Area. Lake Superior, Lake Huron, Lake Michigan, Lake Erie, and Lake Ontario are examples of great lakes. Taken altogether, these five lakes have an area of nearly 95,000 square miles. Five of the great lakes of the Dominion of Canada have an area of more than 32,000 square miles. No other continent has so many lakes of such great size. Lakes but a few square miles in extent are far more numerous than greater ones.

Altitude. Lakes have a great range in altitude, though most large lakes are but a few hundred feet above the sea. The Yellowstone Lake, 7,738 feet above sea-level, and with an area of 140 square miles, is the highest lake of much size in the United States. Lake Titicaca, in South America, is both higher (12,500 feet) and larger (3,200 square miles). A few great lakes are below sea-level. This is true of the Caspian Sea, the Dead Sea, and the Sea of Tiberias, the surfaces of which are 85, 1,268, and 682 feet, respectively, below sea-level. Their elevation is commonly expressed thus: -85, -1,268, and -682 feet.

The bottoms of most lakes are above sea-level, though this is not always the case. The following table gives some facts about twenty-one lakes which are remarkable in their areas, their altitudes, or their depths:

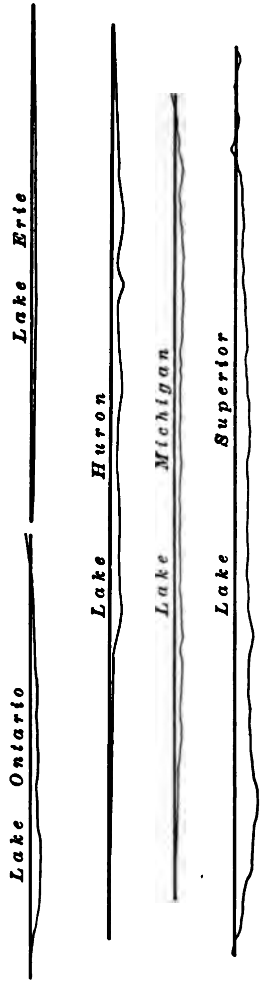


Fig. 252.—Cross-section of the Great Lakes where their waters are deepest. Vertical scale exaggerated about twenty times.

Name.	Approximate area in square miles.	Approximate altitude of surface.[1]	Approximate maximum depth in feet.
Caspian	170,000	-85	3,200
Superior	31,200	602	1,008
Victoria Nyanza	26,000	3,800	240
Aral	25,050	160	1,200
Michigan	22,500	581	870
Huron	22,320	581	700
Nyassa	14,200[2]	1,500	2,300
Baikal	13,000	1,700	4,700[3]+
Tanganyika	12,000	2,700	2,100
Great Bear	11,200	390	270 +
Erie	9,960	573	200 +
Winnipeg	9,400	710	70
Balkash	8,600	900	80
Ontario	7,240	247	738
Chad	6,000[4] to 40,000	900	8 to 20
Titicaca	3,200	12,500	700
Dead Sea	360	about-1,300	1,300[5]-
Garda	189	215	1,135
Chelan	85	1,079	1,500
Como	60	650	1,340
Crater	25	6,239	2,000

Deep as some of the lakes are, the shape of their basins is often very different from that which might be imagined from the mere statement of the depths. Fig. 252 represents the cross-sections of the basins of some of the Great Lakes, but the diagrams exaggerate the depth about twenty times. The basins of many smaller lakes are much more striking in cross-section.

Volume. The volume of water in all lakes is insignificant when compared with that of the sea. If the water of all of them were poured into the ocean, its surface would probably not rise two feet.

Movements of lake water. All lakes are affected by waves, and the water of many lakes moves in other ways also. In some there is a more or less well-defined system of currents (Fig. 253), and in the larger lakes there are slight changes of level from time to time, as the result of changes in atmospheric pressure. If the pressure of the atmosphere is increased in one place, the surface of the water is lowered there and raised elsewhere. If the pressure is decreased in one place, the surface of the water beneath rises, while it falls elsewhere. If such changes are once started, there is some oscillation of level before the water becomes quiet again.

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[1] The negative sign means below sea-level.

[2] Sometimes given as low as 10,200.

[3] Depth of 5,618 feet recently reported.

[4] Range between wet and dry seasons.

[5] Sometimes given as low as 1,171 feet.

Changes of level. The levels of lakes without outlets change a good deal from time to time, according to the amount of precipitation about them. Small lakes may rise several feet in wet weather, and fall as much in times of drought.

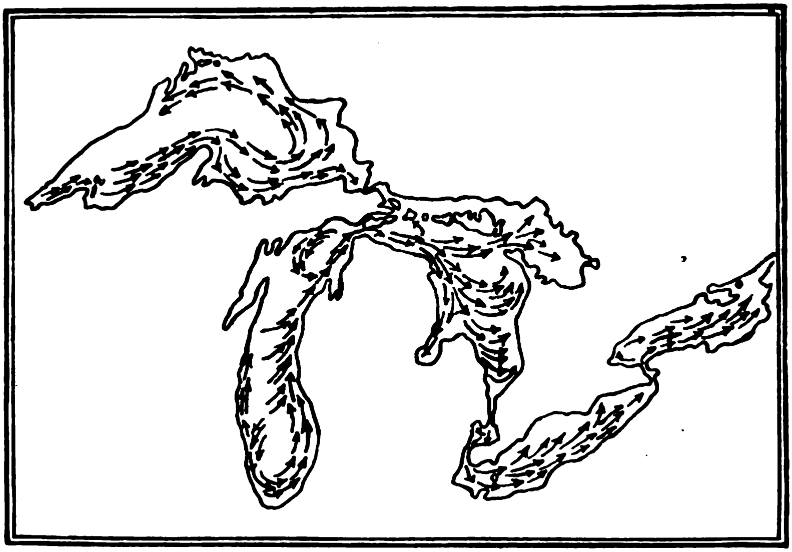

Fig. 253.—Chart showing the general direction of movement of the water in the Great Lakes. (U. S. Weather Bureau.)

Conditions Necessary for the Existence of Lakes

The conditions necessary for the existence of lakes are (1) *depressions without outlets*, and (2) *a sufficient supply of water*. In moist regions most natural basins contain lakes, while the basins of arid regions are often lakeless.[1]

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[1] There are *intermittent lakes*, in the basins of which water is not always present.

The sources of lake water. Lake water comes from rain, melting snow and ice, springs, and rivers. Since springs and rivers depend on rain and snow, the source of lake water may be said to be rainfall and snowfall, or *atmospheric precipitation.*

Changes Now Taking Place in Lakes

Various changes are now taking place in all lakes, and they throw light both on the past and the future of these bodies of water.

The filling of their basins. Lake basins are being filled all the time, and in various ways.

1. By streams and other surface waters which flow into them, carrying in gravel, sand, or mud. Deltas are often built in lakes, and in rare cases they have been extended quite across a narrow lake, separating it into two parts, as at Interlaken, Switzerland (Fig. 254). Large deltas occur at the ends of some of the Finger Lakes of New York, as shown in Pl. XX. Deltas always make lakes in which they are built smaller.

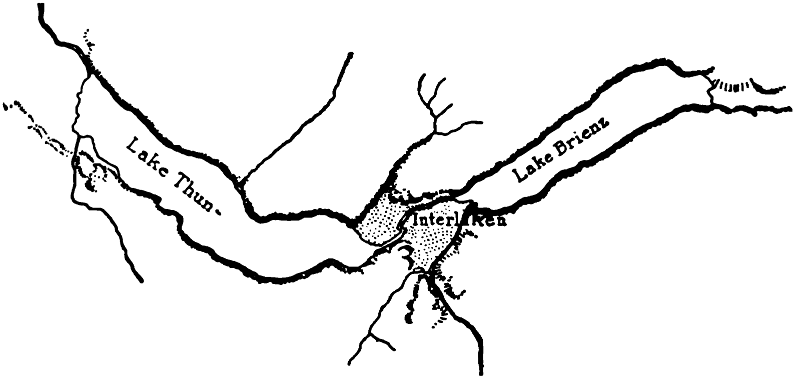

Fig. 254.—Sketch showing the position of the delta on which the village of Interlaken, Switzerland, stands. The two lakes were formerly one, and the lowland on which the village is situated is a delta built across the middle of the original lake, separating it into two parts. The area of the delta-land is shaded with dots.

2. By waves of lakes, which cut into the shore at some points most of the time, and the larger part of the material worn from the land is deposited in the lake. This makes the average depth of the

water less. While rivers and waves are doing more than other agents to fill lake basins, filling goes on slowly in other ways.

3. Numerous shell-bearing animals live in lakes, and when they die their shells are left on the bottom. 4. Plants grow in lakes, especially in the shallow water about their shores, and when they die they fall into the water. 5. Winds blow dust and sand from the land into lakes. In these various ways, all lake basins would be filled in time, and the lakes would then cease to exist.

The lowering of their outlets. The water flowing out of a lake cuts down the level of the outlet, and as this is lowered the depth of the basin below the outlet becomes less. A lake may be destroyed by the lowering of its outlet if its bottom is above base-level; but a lake whose bottom is below base-level can never be destroyed by the lowering of its outlet. In such cases, filling and cutting may do what cutting alone could not. As a result of the cutting down of their outlets and of the filling of their basins, all existing lakes must finally become extinct. New ones may be formed, however, as old ones are destroyed.

Lakes are occasionally destroyed by drying up. This sometimes results from a change of climate, but it may also result from the turning away of inflowing waters.

Extinct Lakes

Many lakes have become extinct, but their sites may be recognized by various features. If a lake became extinct by having its basin filled, its former position is marked by a flat (Fig. 255) covered with sediment of the sort deposited in lakes. Such a flat is a *lacustrine plain.* Lacustrine plains occur in mountains, on plateaus, or on plains of a larger type. If a lake became extinct by the lowering of its outlet or by evaporation, its former bed might not be flat.

The former borders of an extinct lake are often marked by various shore features, such as deltas, terraces, beaches, shore-cliffs, etc., to be studied in the later part of this chapter. All features developed by lakes about their shores will be destroyed sooner or later by the agents of erosion. They last longer in dry regions than in places where rain is plentiful.

The Origin of Lake Basins

Lake basins have come into existence in many different ways. Most of them are the result of gradational processes, but some of them are made in other ways.

By gradation. Rivers, waves, and glaciers produce lake basins, and some of these agents produce them in several different ways.

Reference has already been made (p. 147) to the more important types of *lakes formed by rivers.*

Waves and shore currents give rise to lakes by making deposits of gravel and sand across the lower ends of drowned valleys or other narrow bays. Numerous examples are found along many coasts (Fig. 1, Pl. XIX and Fig. 251).

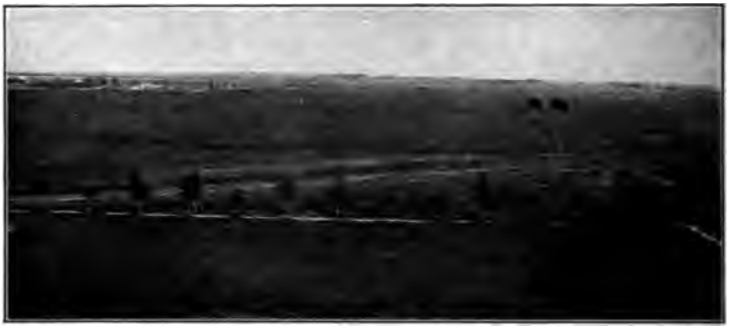

Fig. 255.—A part of the flat of Lake Agassiz, Moorhead, Minn. (Goode.)

Lake basins produced by glaciers are very numerous, as we have seen (p. 205), and some of the ways in which the ice gave rise to them have been explained in preceding pages.

Slumping (p. 66) *sometimes makes lake basins*, especially when the material sliding down obstructs a valley. Such a lake, five miles long and more than seven hundred feet deep, was formed on the upper Ganges, in 1892. Two years later the dam which held back the water broke, and the resulting flood wrought great destruction in the valley below.

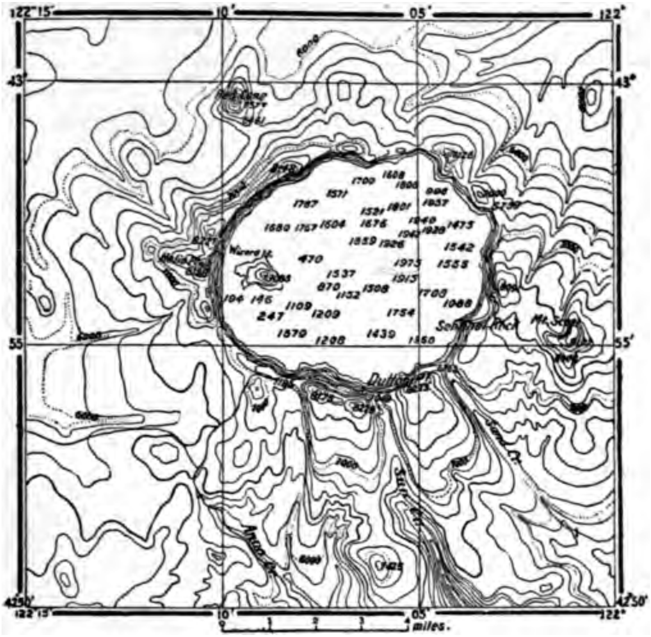

Fig. 256.—Map of Crater Lake, Ore. Contour interval 200 feet. The figures which appear on the surface of the lake represent the depths of water in feet. Lake surface 6,239 feet above the sea-level. (U. S. Geol. Surv.)

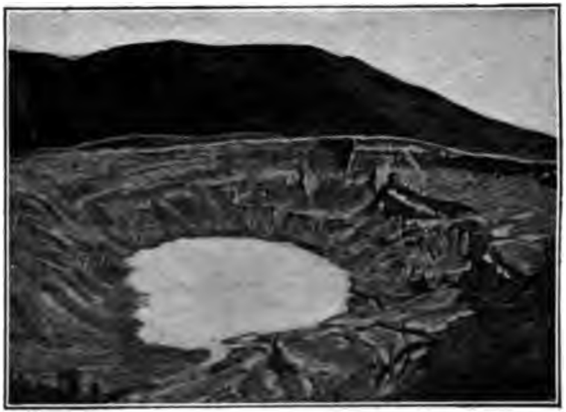

Fig. 257.—The crater lake of the volcano Poas, Costa Rica.

Wind-driven sand sometimes scours out small depressions which hold pools of water, though the basins of lakes are not known to have originated in this way. The sand deposited by wind is sometimes piled up about low places, enclosing them, thus giving rise to marshes, ponds, and even lakes.

By vulcanism. A few lake basins were formed by vulcanism. Some of them are in the craters (p. 239) of volcanoes which are no longer active (Figs. 256 and 257). In other cases flows of lava have obstructed valleys, ponding the water above.

By movements of the earth's crust. Other lake basins have come into existence by movements of the earth's crust. These movements will be studied in a later chapter, but it may be stated here that if an area sinks, as has sometimes happened, it may give rise to a depression fit for a lake (Fig. 258). The sinking may come about in various ways, as we shall see.

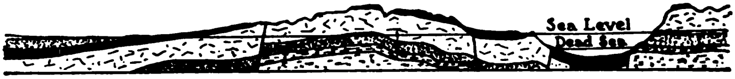

Fig. 258.—Section across the mountains of Palestine, to the mountains of Moab, showing the position and relations of the Dead Sea.

The Climatic Effects of Lakes

The great number of lakes in the northern parts of the United States and Europe have some little influence upon the climate of the regions in which they occur. They increase its humidity to some slight extent at least, and, since water is heated less rapidly than the land and also gives up its heat less readily, the lakes have the effect of tempering the climate. Until they freeze over, they tend to keep the temperature of their surroundings a little higher than it would otherwise be in the autumn and early winter, and they tend to reduce the temperature of spring. The climatic effects of a small lake are so slight as not to be noticed, but the effects of large lakes such as Michigan or Superior, are distinctly felt. The temperature effects of great lakes are felt chiefly on the sides toward which the prevailing winds blow.

Economic Advantages and Disadvantages

Are lakes helpful or harmful to mankind? Various considerations have a bearing on this question.

1. The Great Lakes make cheap transportation possible, for freight can be carried by boats more cheaply than by rail. In this way lakes serve a good purpose. 2. Many cities, like Chicago, draw their water-supply from lakes. 3. Lakes yield fish which are of some importance as food. 4. Large lakes affect the climate and so modify, to some extent, the crops which may be raised about them. Thus the prevailing westerly winds change the climate of the east shore of Lake Michigan so as to make it favorable for fruit-growing, while the west side of the lake is not adapted to fruit. In these and other ways the lakes seem to benefit mankind.

On the other hand, it is to be remembered that lakes cover land, much of which might have been good farming land if the lake had not been present. Lake Michigan, for example, has an area of about 22,450 square miles. The value of such an area (more than 14 millions of acres) of good farming land would be hundreds of millions of dollars. Small lakes are of little consequence to commerce, and the modifications of climate which they produce are slight.

Lakes have a value not to be estimated commercially. They beautify the landscape, and afford the means for rest and recreation which could not well be spared. The actual value of such considerations cannot be estimated in dollars and cents.

Lakes seem to have been of advantage to primitive peoples, for the earliest European civilization grew up about the lakes of Switzerland, while the lakes of Mexico and Peru were the seats of the ancient civilizations of those countries.

SALT LAKES

A few lakes are salt, and some salt lakes are the descendants of lakes which were fresh. Great Salt Lake is an example. This lake is very shallow and occupies the lowest part of a basin of great size. The lowest point in the rim of this basin is about 1,000 fee above the present lake; but water once filled the basin up to this level, for shore-lines and deltas are found about its border at many points. When the lake stood at this level, it had an outlet to the northward over to Snake River. In the sands and muds deposited

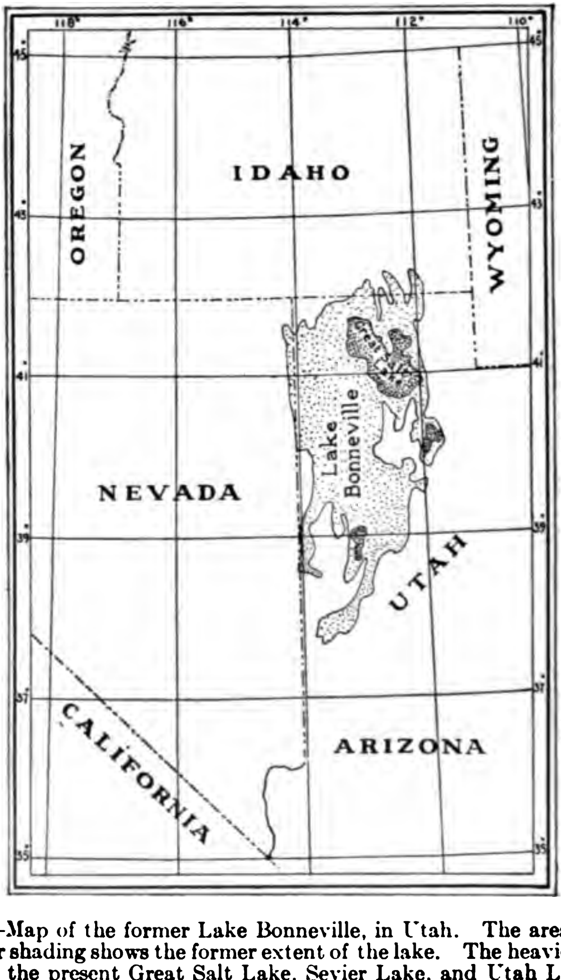

Fig. 259.—Map of the former Lake Bonneville, in Utah. The area with the lighter shading shows the former extent of the lake. The heavier shading shows the present Great Salt Lake, Sevier Lake, and Utah Lake, all of which occupy the deeper spots in the bottom of the former Lake Bonneville. (U. S. Geol. Surv.)

at this high stage of the lake, there are shells of fresh-water snails, and remains of other fresh-water animals. These show that the water was then fresh. This great lake, though now extinct, has been named *Lake Bonneville* (Fig. 259). When it was largest, it covered an area of about 17,000 square miles.

After the lake had stood at this level for a time, the climate of this region seems to have become so dry that evaporation from the surface of the lake was more than the inflow of streams and the rainfall on the lake, and so the level of the lake became lower. As the water evaporated, the mineral matter which it held in solution was left behind. Salt was one of these substances, and as more and more water evaporated, the saltness of that which remained increased. This condition of things went on until the former great lake was reduced to the relatively small Great Salt Lake of the present, with an area of about 2,000 square miles, and an average depth of only about 15 feet. Its waters are now saturated with salt, and much salt has been deposited from them.

If the climate of this region were to become moist again, so that the intake of fresh water was greater than the evaporation from the lake, the level of the lake would rise, and the saltness of its water would become less. If it rose till it overflowed, the continued inflow of fresh water, and the continued outflow of the diluted salt water, would result in a constant freshening of the lake, and it would finally contain so little salt that it could not be tasted. The lake would then be called fresh.

Other lakes in the region east of the Sierra Mountains have undergone the same history. The shore terraces, deltas, etc., of these former lakes of the Great Basin are still very distinct. The time since the lakes existed has therefore not been long enough for the erosion of this arid region to destroy or even to greatly obscure them.

Salt lakes, and the sites of former salt lakes, furnish much of the salt of commerce. Great Salt Lake was estimated, a few years ago, to contain 400,000,000 tons of common salt, besides large quantities of other mineral matter. Utah produced more than 400,000 barrels of salt in 1902, and 253,829 (value $321,301) in 1904.

The Topographic Features of Shores

Reference has been made already to certain topographic features of lake shores, but the topic is of so much importance that it must be studied a little more in detail.

Waves, currents, rivers, winds, glaciers, ice formed along the shore, and various other agencies are working on the shores of seas and lakes, and each has some effect on the coast-line. Of these, the waves, and the movements of the water to which the waves give rise, are the most important.

Gradational Changes Now Taking Place along Shores

1. Waves, undertow, shore currents. Waves are cutting in on some parts of the shore of almost every lake, and they are more active when the wind blows than at other times. Away from the shore, the water in a wave does not move forward. Some idea of its motion may be gained from a field of waving grain or grass, where each moving stem is fixed to the ground, though wave after wave crosses the field. Some conception of the motion may also be gained if one end of a long piece of rope is fixed, while the other is shaken up and down. Successive waves travel from the end shaken to the end which is fixed. In these illustrations the grain and the rope come to rest just where they started. Fig. 260 gives some idea of the nature of the movement of the water in the waves where the water is deep. The curved line represents the crest and trough of a wave, while the little circles show the path of each particle of water in the wave.

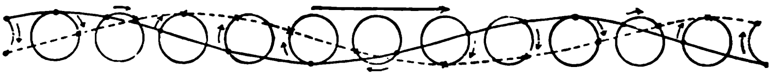

Fig. 260.—Diagram to illustrate the movement of water in waves. The small circles represent the movement of water particles.

The amount of motion in a wave is greatest at the surface. It diminishes rapidly below, and disappears altogether before the bottom of deep water is reached. Foundations for piers and other structures beneath the water are rarely disturbed by waves more than a few feet below the surface.

When a wave advances into shallow water near the shore, its motion changes. This is because the motion of the water in the lower part of the wave is hindered by contact with the bottom. The wave is then said to "drag bottom." The velocity of the bottom of the wave is checked by dragging on the bottom, and its top then pitches forward, as *surf* (Fig. 261). In strong winds and in shallow water, therefore, there is a distinct forward movement of some of the water of a wave.

The water thrown against the shore in the *wave* runs back again, and this from-shore motion is the *undertow*. Where waves come in against a shore obliquely, they produce a movement of water along the shore. This is the *shore* or *littoral current*.

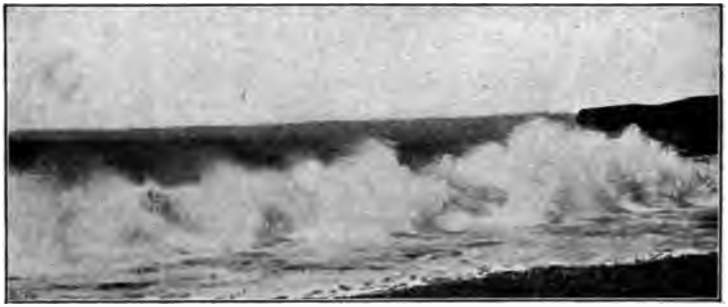

Fig. 261.—Surf, Coronado Beach, Cal.

The waves, the undertow, and the shore currents all affect the shore. All of them wear the bottom in shallow seas, and the waves wear away the land. All the sediment eroded from the shore, or from the shallow bottom near it, is soon deposited. Whether the moving water erodes or deposits, it affects the outline of the coast.

Erosion by waves. The force of the wave as it is hurled against the shore is often great. In the open sea, storm waves often have a height of 20 to 30 feet, and in rare cases even 50. The surf is sometimes thrown up to heights of more than 100 feet with force enough to destroy lighthouses. The windows of the Dunnet Head lighthouse on the coast of Scotland are said to have been broken at heights of 300 feet above sea-level during severe gales. It has been estimated that the strength of waves on the coast of Great Britain is sometimes as much as three tons per square foot, and that the average for winter waves is about one ton per square foot. Such waves would move masses of rock tons in weight. It is clear, therefore, that the force of waves is great enough to wear shores, even of solid rock. The waves of lakes are never so strong as the great waves of the sea, but the storm waves of large lakes have great force, and sometimes wash away piers, breakwaters, and shore pavements, even in a single storm.

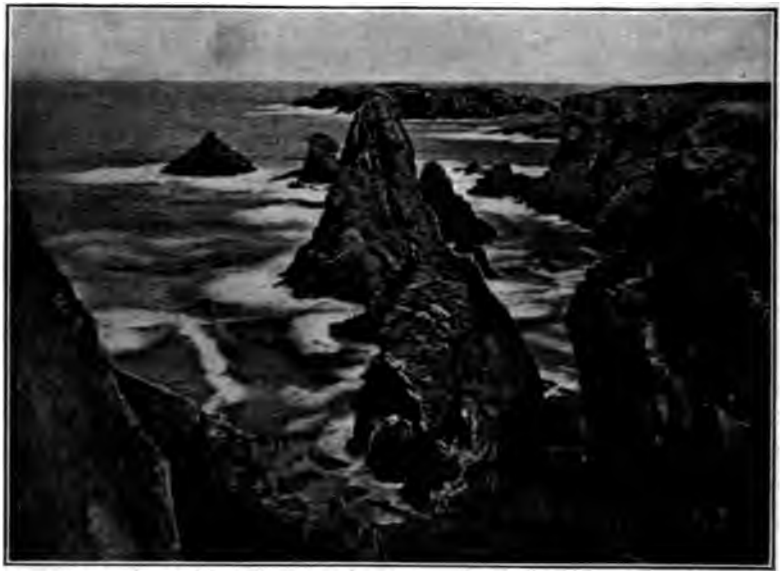

Fig. 262.—A rocky coast developed by wave erosion.

Let us think of a regular shore composed of rock of unequal hardness. Waves would wear the softer rock of such a shore more than they would the harder rock, and the coast would be made irregular. The irregularities would become greatest where the waves are strongest.

Again, let us think of a very irregular coast, the rock of which is all of equal hardness. The waves would wear the projecting

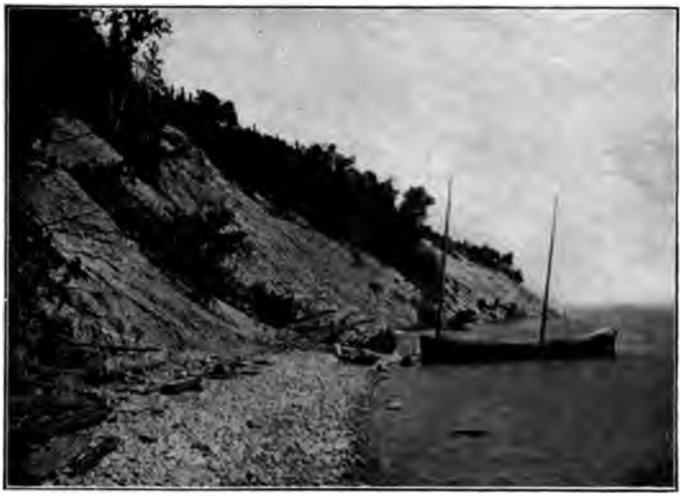

Fig. 263.—High cliff with beach; shore of Lake Michigan. (U. S. Geol. Surv.)

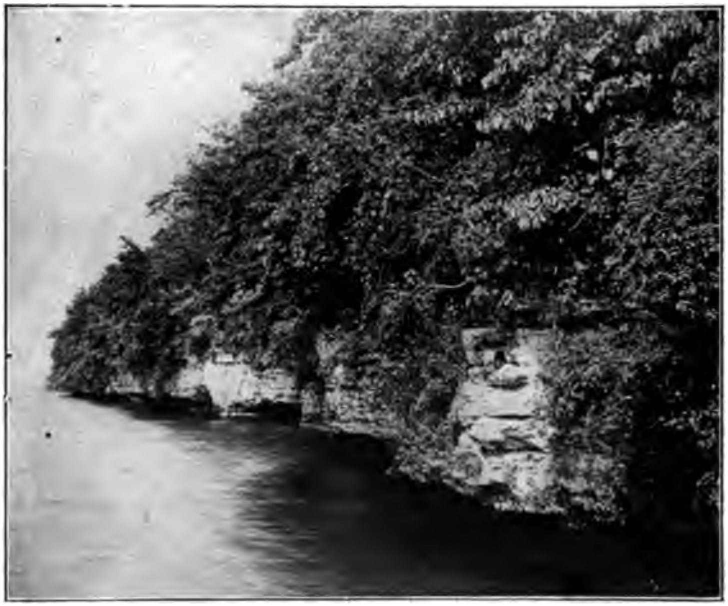

Fig. 264.—Cliff made by undercutting of waves. Lake Mendota, Wis. (Willi

points of such a shore more than they would wear the heads of the bays. Wave erosion, therefore, tends to make a very irregular coast less irregular, unless the projecting points are of harder rock than other parts of the coast.

The rock along most shores is of different degrees of hardness, but within short distances the differences are not often great.

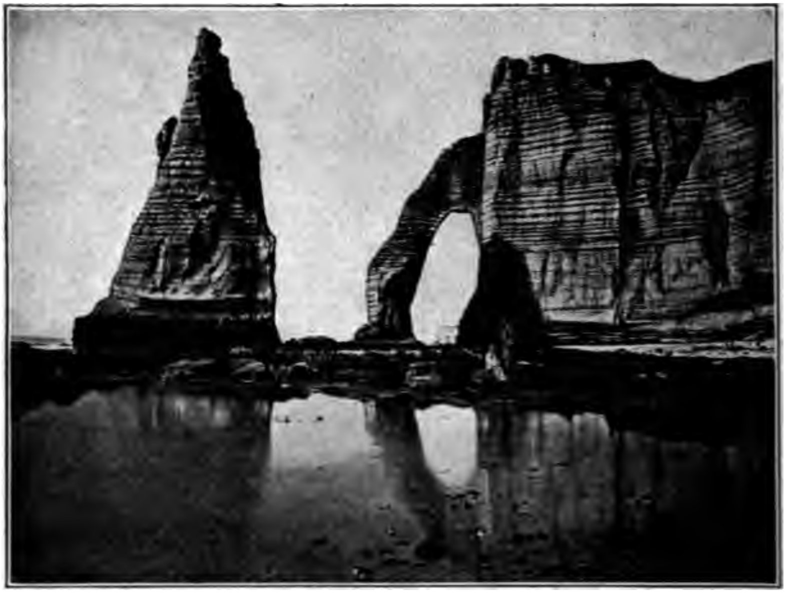

Fig. 265.—A chimney rock and an arch on the coast of France. (Neurdein.)

Wave erosion, therefore, tends to make small irregularities of shore-line, but not great ones. The irregularities are larger where the waves are strong, and where the hardness of the rock is very unequal. Irregularities developed in this way are very numerous on the shores of lakes and seas.

Where waves cut in upon the land along their shores they make steep slopes, or cliffs (Figs. 263, 264, and 265). Such cliffs on the sea-shore are called *sea cliffs*, and those on the shores of lakes may be called *lake cliffs*. Shore cliffs will be high (Fig. 266) if the waves cut into high land, and low (Fig. 267) if they cut into low land Cliffs along shores indicate that the waves are now cutting into the land, or that they have recently done so. Their absence indicates the absence of recent wave-cutting. Slumping often accompanies wave erosion.

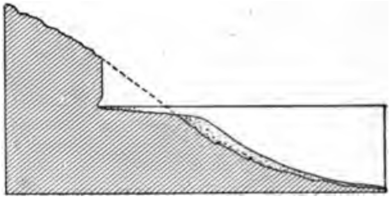

Fig. 266.—Diagram illustrating high sea cliff It shows also a submerged terrace, due partly to wave-cutting, and partly to building.

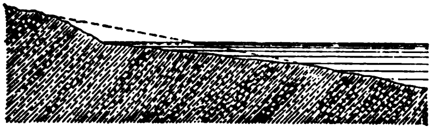

Fig. 267.—Diagram showing a low sea cliff.

The cliff developed by wave-cutting is often bordered by a *wave-cut terrace* a little below the surface of the water (Fig. 266). The width of this terrace sometimes shows, in a rough way, how much the water has advanced on the land by the cutting of its waves. By rise of the land, or by sinking of the sea, the terrace may become land (Fig. 268).

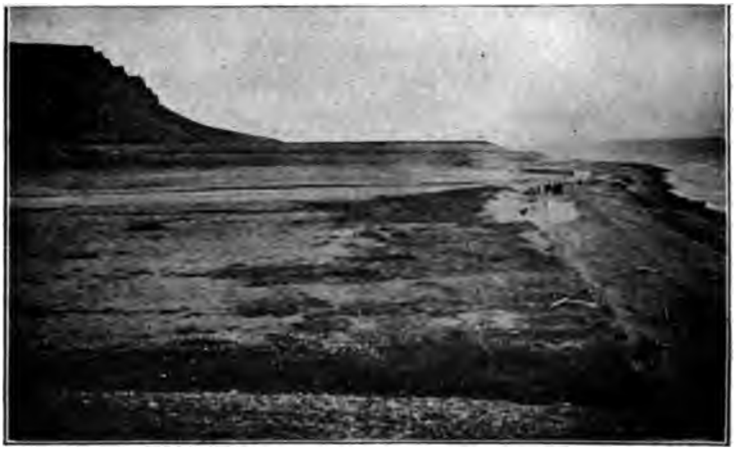

Fig. 268.—A wave-cut terrace now well above the sea. Either the land has been raised or the sea-level has sunk since the terrace was cut. Seward Peninsula, Alaska. (U. S. Geol. Surv.)

Deposition by waves, shore currents, etc. The material worn from the land by waves, or brought to the shore by rivers, is shifted about by waves, undertow, and shore currents, but it finally comes to rest. If left at the shore-line it makes a *beach* (Fig. 269). If carried farther out into the water it takes on other forms.

Waves often build *reefs* or *barriers* a little out from the shore-line. They are developed near the line of breakers, where the incoming wave leaves much of the sediment which it is moving in toward the shore. The undertow may contribute sediment to the reef, by carrying it out from the shore. There are sometimes several such reefs along a coast, parallel to one another and to the shore. They are often troublesome to navigation.

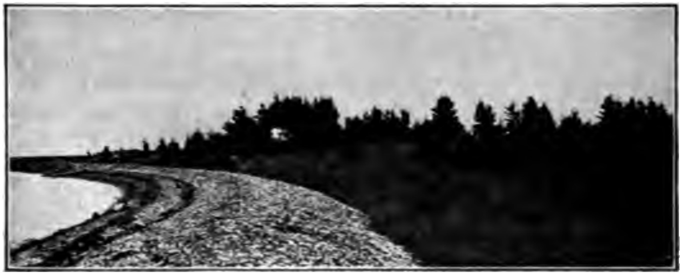

Fig. 269.—A barrier beach, shutting in a marshy tract behind it. Lasells Island, Penobscot Bay, Me. (Bastin, U. S Geol. Surv.)

After a reef is developed, waves may build its crest above the surface of the water, converting it into land (Fig. 270). This seems to have been the origin of many of the low, narrow belts of sandy land parallel to coasts, with marshes and lagoons behind them. This type of irregularity is illustrated by the coast of the United States at various points between New York and Texas (Fig. 134).

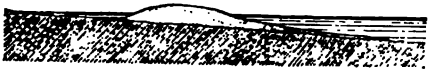

Fig. 270.—Section of a barrier. (Gilbert, U. S Geol. Surv.)

Shore currents move sediment along the coast, but where such a current reaches a bay, it does not commonly follow the outline of the bay. It tends rather to cross it in the direction in which it was previously moving. Under such circumstances it often builds an embankment of gravel and sand across the bay. Such embankments are *spits*. Currents do not build spits above the water, but waves may build them up into land by washing material from their slopes up to their tops (Figs. 134 and 271). After they become land, the wind may build dunes upon them (p. 32). When spits cross bays they become *bars* (Fig. 271).

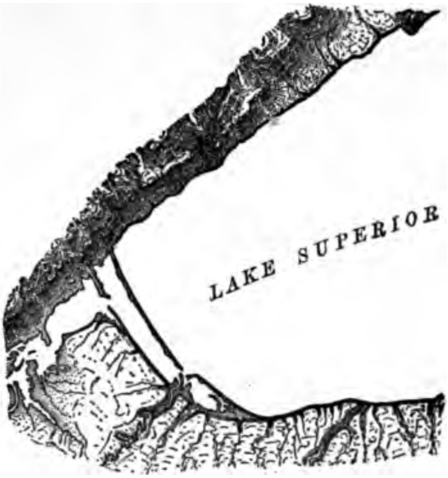

Fig. 271.—Map of the head of Lake Superior. (U. S. Geol. Surv.)

If the *shore drift*, as the sand and gravel of the beach is called, is deposited against the mainland, it may cause the land to encroach upon the water. A coast-line developed by deposition is in contrast with one developed by erosion, for the former has no sea cliff.

Reefs and spits and the land to which they give rise often increase the irregularity of the coast-line greatly for a time (Fig. 134); but they represent the first step toward regularity, for after the reefs have become land, the lagoons behind them are likely to be filled with sediment washed down from the land or blown in by the wind (Fig. 272). When the lagoon is filled, the shore-line is much more regular than before; but the first effect of the making of the reef-land is to make the coast more irregular.

Deposits of gravel and sand are sometimes made between a mainland and islands near it. Nahant Island, on the coast of Massachusetts, and the Rock of Gibraltar, on the coast of Spain, have been thus "tied" to the mainland (Pl. XXI).

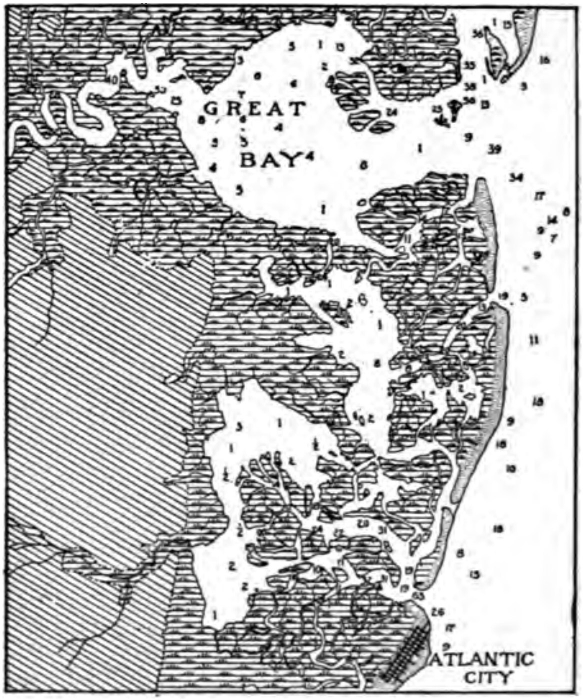

Fig. 272.—Sketch-map of a part of the New Jersey coast. The dotted belt at the east is the barrier modified by the wind. The area marked by diagonal lines is the mainland; the intervening tract is marsh-land. The numbers show the depth of water in feet. Scale: ¼ inch = 1 mile.

Bars, reefs, etc., often hinder the movements of ocean vessels, especially when they tend to close the entrance of harbors. A spit which does not obstruct the entrance to a harbor, on the other hand, is sometimes an advantage, since it breaks the force of the incoming

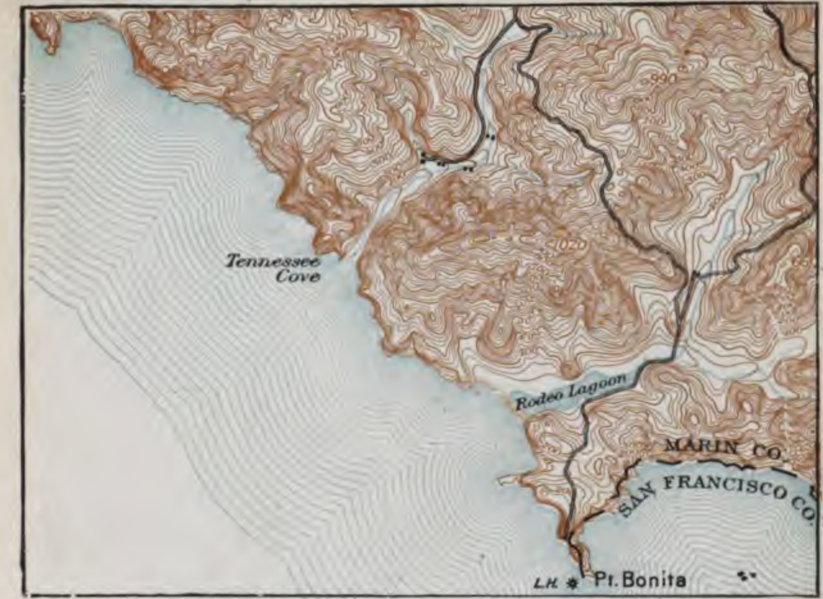

FIG. 1.—A coast line developed chiefly by wave erosion. Scale about 1 mile per inch. (Tamalpais, Cal., Sheet, U. S. Geol. Surv.)

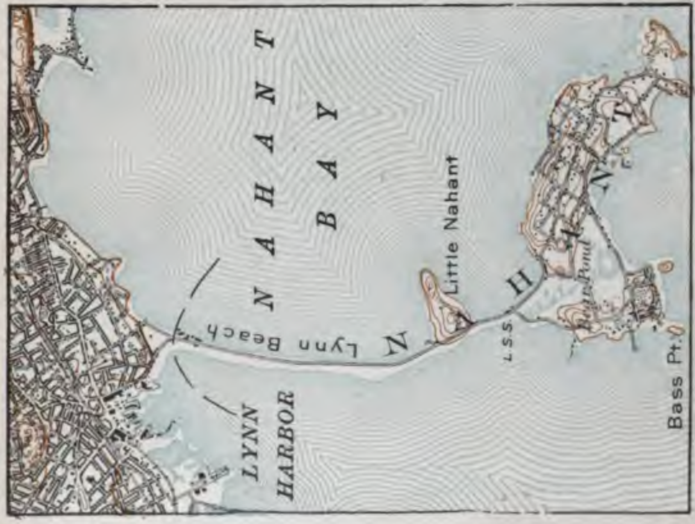

FIG. 2.—An island tied to the mainland by a "beach." Scale about 1 mile per inch. (Boston Bay, Mass., Sheet, U. S. Geol Surv.)

waves in storms, and so helps to form a harbor. Spits which form harbors have determined the location of numerous villages and cities. Erie, Pennsylvania, is an example.

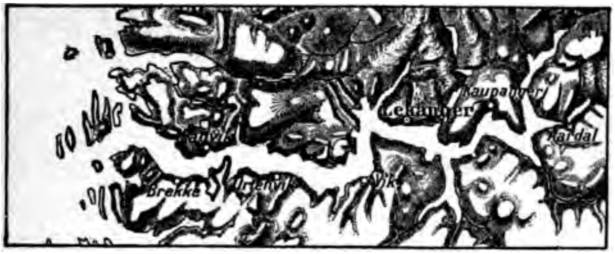

Fig. 273.—The Sogne Fiord, coast of Norway. (Robin.)

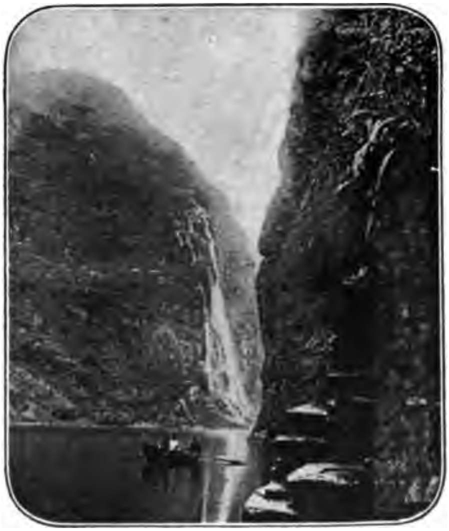

Fig. 274.—Fiord on the coast of Norway.

2. **Rivers.** River erosion has little effect upon the shore-line, but the deposition of sediment brought down by streams is of much consequence in changing the outline of the land, especially where deltas are formed. The delta of the Mississippi (Fig. 159), for

example, is a great irregularity, and it has many smaller irregularities about its borders. Deltas in lakes show the same general features, though on a smaller scale. Delta-land is always low.

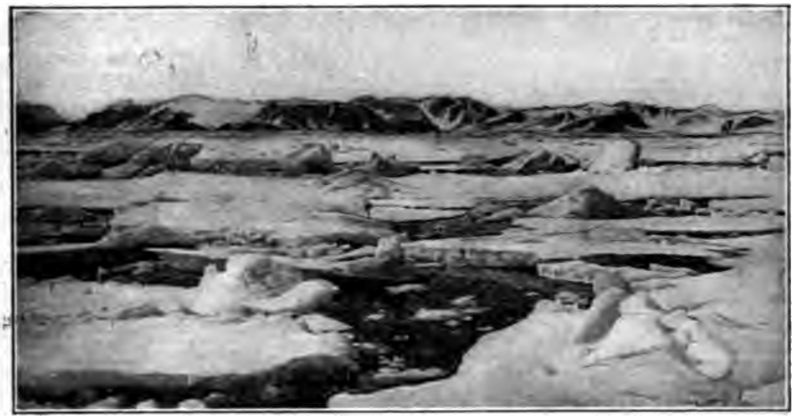

Fig. 275.—Sea ice on the western coast of Spitzbergen.

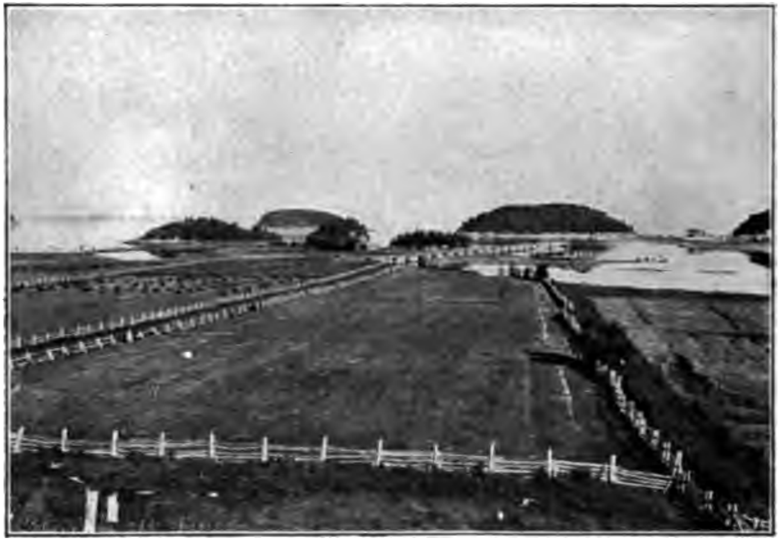

Fig. 276.—A coastal flat, village of Bic, Quebec. (U. S. Geol. Surv.)

3. **Winds.** The wind often makes dunes of the dry sand along shores, but this does not commonly change the outline of the land area to any great extent.

4. **Glaciers.** Glaciers descend to the level of the sea in some places, as in Greenland and Alaska. Where this is the case, they usually move down to the sea through valleys. If the ice is thick, the glaciers gouge out the valleys, sometimes to great depths below the level of the sea. When glaciers in such valleys melt, the lower ends of the valleys become narrow bays, or *fiords*. This is the explanation, or at least a part of the explanation, of the many fiords of Norway (Figs. 273 and 274), Alaska, Greenland, and Chile, and some other coasts.

5. **Shore ice** is another agent which works on coasts, but does not greatly modify their outlines.

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10. The following more extended treatises may be studied with profit and their illustrations are valuable if time does not permit the use of the text: DILLER, *Crater Lake:* Prof. Paper No. 3, U. S. Geol. Surv.; FENNEMAN, *Lakes of Southeastern Wisconsin:* Bull. 8, Wis. Geol. and Nat. Hist. Surv.; GILBERT, *Topographic Features of Lake Shores,* in 5th Ann. Rept. U. S. Geol. Surv.; *Lake Bonneville:* Mono. I., U. S. Geol. Surv.; RUSSELL, *Lake Lahontan:* Mono. XI, U. S. Geol. Surv.; *Mono Lake:* 8th Ann. Rept. U. S. Geol. Surv.; UPHAM, *Lake Agassiz:* Mono. XXV, U. S. Geol. Surv.

CHAPTER VII

VULCANISM

VOLCANOES

A volcano is a vent in the earth's crust out of which hot rock comes. The hot rock may flow out in a liquid form (called *lava*), or it may be thrown out violently. In the latter case it may be solid when it starts, or it may be liquid; but even in the latter case it is likely to become solid by cooling before it falls to the surface of the land.

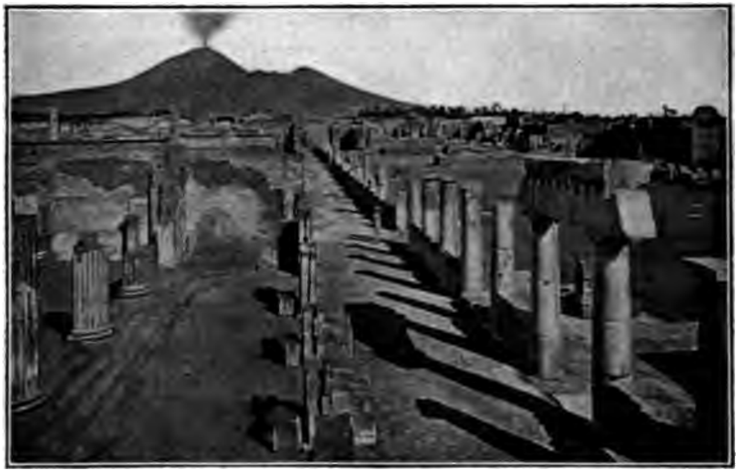

Fig. 277.—Vesuvius and the ruins of Pompeii. (Brogi.)

The rock material which comes out of a volcano is generally built up into a cone (Fig. 277). The cones may be mounds, high hills, or even high mountains. Though they are the products of volcanoes, the cones are themselves often called volcanoes. The vent from which lava flows makes a cone with gentle slopes, while the volcano from which solid matter is thrown makes a cone with steeper slopes. Some volcanoes send out both liquid and solid rock. Both may be issuing at about the same time, or lava may flow out at one time and solid rock be thrown out at another. Quantities of gases and vapors, some of them poisonous, are discharged along with the hot rock.

So long as a volcano is active there is likely to be a hollow, called *the crater* (Fig. 278), in the top of its cone. Craters vary greatly in size. Some of them are but a small fraction of a mile across, while others are much larger. That of Mauna Loa (Hawaii), is two miles long and three wide. An opening leads down from the crater to the source of the lava, at an unknown depth. The sizes and shapes of these openings cannot be seen while the volcano is active, but they probably vary much in size and shape, and perhaps in length as well.

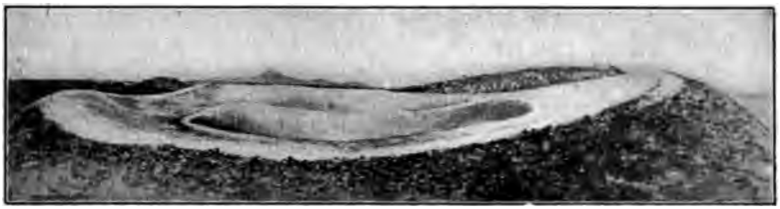

Fig. 278.—Sketch of the crater of the cinder cone near Lassen Peak, Cal. The funnel is 240 feet deep. (U. S. Geol. Surv.)

From the following accounts of a few active volcanoes, many of the features of volcanic action will be gathered.

Stromboli. The cone of this volcano is an island four or five miles in diameter, in the Mediterranean Sea, north of Sicily. The cone is built up from the bottom of the sea, and is about a mile high, though but little more than half of it projects above the water. About 1,000 feet below its top there is an opening in the side of the mountain, from which steam constantly issues. At a distance the steam looks like smoke.

It is sometimes possible to climb up to the crater and look in.

Its floor is then seen to be black rock, which is really hardened lava. In this hardened lava there are deep cracks, and from some of them steam puffs out somewhat as from an engine. In other cracks boiling liquid lava may be seen. Bubbles form in it and burst, much as bubbles form and burst in a pot of boiling mush. When they burst, fragments of the lava of which the bubbles are composed are hurled hundreds of feet into the air, and fall on the slopes of the cone. These fragments may be white-hot or red-hot when they are shot out, but they cool quickly in the air, and cease to glow before they have fallen to the surface of the cone. At night the glowing lava in the cracks of the crater's floor lights up the clouds of steam which hover over the mountain. It is for this reason that Stromboli is known as "the lighthouse of the Mediterranean." The eruptions of Stromboli are occasionally so violent that the roar of the escaping steam may be heard for miles, while the lava is hurled so high and so far that it is scattered not only over the entire mountain, but into the surrounding sea. Stromboli is one of many volcanoes which have existed in this part of the Mediterranean Sea. Some of the others, such as Etna, are still active, while others are *dormant* (quiet) or *extinct*.

Vesuvius. Vesuvius is probably the best known volcano. Its cone is a mountain about 4,000 feet high, on the shore of the Bay of Naples, about 10 miles from the city of the same name. The present cone of the volcano (Fig. 277) rises within the half-destroyed rim of an older and much larger crater.

Previous to 79 A. D. Vesuvius was, so far as then known, only a conical mountain, in whose summit was a deep crater three miles in diameter. The slopes and even the bottom of the crater were covered with vegetation. In that year a terrible explosion occurred, which blew away half the rim of the crater. Much of the rock blown out was broken into such small pieces as to constitute *dust* (often called *volcanic ash*), and as it fell on the surrounding country, it buried and destroyed not only plants, but even cities. Pompeii, a city of some 20,000 inhabitants, was thus buried, and about 2,000 of its people were killed. Heavy rains accompanied or followed the eruption. Falling on the volcanic dust, the water gave rise to streams of hot mud. Herculaneum was overwhelmed by such a stream.

The present cone of Vesuvius was built up inside the remnant of the rim of the older cone after this eruption.

Since the outburst of 79, Vesuvius has had other violent eruptions, separated by periods when it was quiet, or when its activity was mild. The eruption of 1631 was especially violent, destroying 18,000 lives. Another eruption of great violence occurred in 1872. For several months before there had been slight eruptions, during which steam and small fragments of rock issued from the crater, and lava flowed from the cracks on the mountain-side. The activity gradually increased in violence until April, when two huge fissures and several smaller ones opened on the flanks of the cone, and from them great streams of lava flowed into the neighboring valleys, overwhelming two villages. At the same time, two large openings were made at the summit, from which enormous quantities of steam, dust, and masses of molten rock were hurled 4,000 feet or more into the air, with a noise which could be heard for many miles. At night the cloud overhanging the mountain was brightly lighted by the glowing lava in the crater. The discharges continued with great violence for four days, and at the same time earthquakes were felt throughout the entire region.

After the eruption was over, two craters 750 feet deep, with nearly vertical sides, were found at the top. An enormous amount of loose material had accumulated on the sides of the mountain, and the lava which issued from the fissures lower down covered an area of one and four-fifths square miles, to an average depth of 13 feet.

Vesuvius was again disastrously active in the spring of 1906.

The history of the recent eruption is summed up by Professor Jaggar as follows: "In 1904 there was a lava-flow which stopped in September of that year. In May, lava flowed from a split in the northwest side of the cone and continued in active motion throughout the year.

"It ceased flowing at the time when the present eruption opened a new vent on the south side of the cone. On April 4, 1906, a splendid black 'cauliflower' cloud rose from the crater (Fig. 279). On April 4th, 5th, 6th, and 7th, lava mouths opened along the southern rift above mentioned, first 500 feet below the summit, then 1,300 feet lower, and finally 600 feet lower still, all in the same radial line. The lowest mouth was more than half-way down the mountain, and from this orifice came the destructive streams. It should be borne in mind that these flows are not floods of lava which cover the whole slope of the mountain, but relatively narrow snake-like trickles, none the less deadly when they push their way through a closely built town. The molten rock crusted over and cracked, making a tumble of porous boulders at its front.

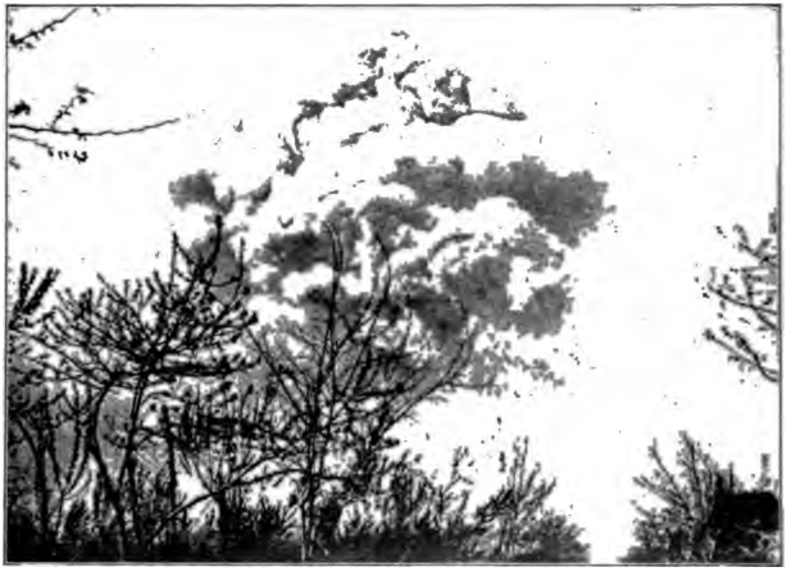

Fig. 279.—The cauliflower cloud above Vesuvius, April 7, 1906. (Jaggar.)

"At 8 P. M., April 7th, a column of dust-laden steam shot up four miles from the crater vertically. The cloud snapped with incessant lightnings. New lava mouths opened, and the flows moved forward, crushing and burning and swallowing parts of Boscotrecase, the stream forking so as to spare some portions of the town. Meantime torrents of ashes fell on Ottajano, on the opposite side of the volcano, and many roofs collapsed (Fig. 280) and lives were lost. . . .

"Boscotrecase was ruined wholly by lava; Ottajano by falling gravel. Boscotrecase is traversed in two places by the clinkery lava stream, and in some cases houses were literally cut in two. The stream of lava had forked about a spur of the mountain, leaving the higher land with its vineyards untouched. The lower land with its town was invaded. There is so little timber in the Italian masonry construction that the uninvaded part of the town was not burned at all. At Ottajano the roofs fell in under the weight of sand and gravel (Fig. 280). The roofs were largely flat or slightly sloping tiled affairs. The ash and lapilli reached a depth of three feet on level surfaces. The roofs carried the walls with them in many cases, but there was no significant earthquake. There was no fire, destructive lightning, nor strong wind. The persons who perished were all found in the houses, where the sole cause of death was entombment in the ruins."

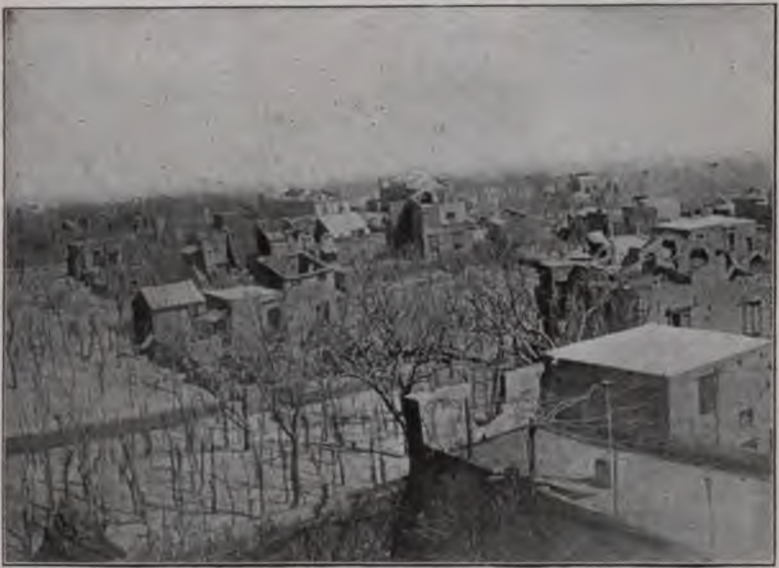

Fig. 280.—The ruins of Ottajano. Some of the roofs have fallen in under the load of ashes.

Krakatoa. One of the most violent and destructive volcanic explosions of which there is historical record was that of 1883, in Krakatoa, a volcanic island in the Strait of Sunda, between Sumatra and Java.

Previous to the eruption, the island had been shaken by earthquakes and minor explosions for some years. On the morning of the 27th of August there was a series of terrible explosions, by which about two-thirds of the island was blown away (Fig. 281), and the sea is now 1,000 feet deep where the center of the mountain formerly stood. Enormous sea-waves were formed, and spread to Cape Horn, and possibly to the English Channel. On the shores of the neighboring islands the water rose 50 feet, causing great destruction. More than 36,000 persons perished, mostly by drowning, and 295 villages were wholly or partially destroyed. The sky over the island and the bordering coasts became black as night from the clouds of dust. It was estimated that steam and dust were shot up into the air 17 to 23 miles. The finest particles of the dust were carried by the wind to all parts of the earth, and it is thought to have been two or three years before all of it had fallen from the air. This dust in the air caused brilliant sunsets, and by knowing the places where the red sunsets appeared from day to day, it was estimated that some of the dust completed a circuit of the earth in about 15 days. The sound of the explosion was heard in southern Australia, 2,200 miles away.

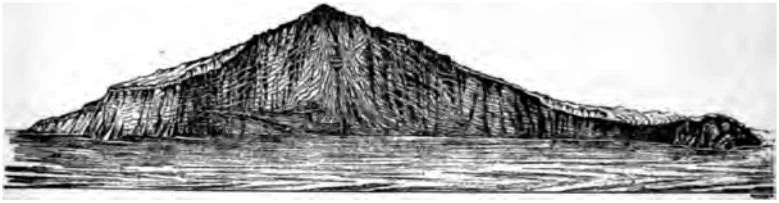

Fig. 281.—Krakatoa after the eruption of 1883.

The cause of this awful explosion was probably the same as that of the milder eruptions of Stromboli, that is, the sudden escape or explosion of superheated steam.

There are many other volcanoes, active and extinct, in the vicinity of Krakatoa.

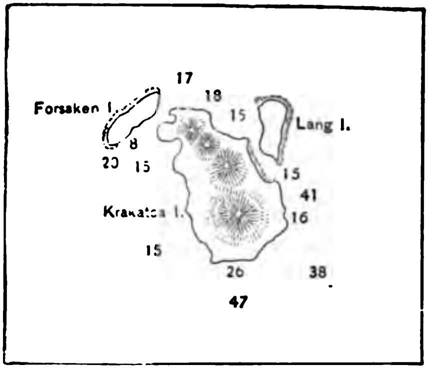

Fig. 282.—Krakatoa Island and surroundings before the eruption of 1883. The numbers indicate the depth of the water in fathoms.

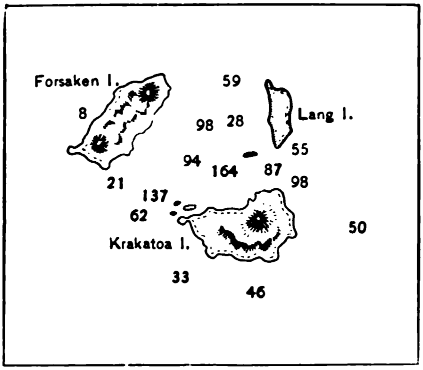

Fig. 283.—Krakatoa Island and surroundings after the eruption of 1883. The numbers indicate the depth of the water in fathoms.

Mont Pelée and the Soufrière. The volcano of Mont Pelée is situated on the island of Martinique (Fig. 284), one of the Lesser Antilles, at the eastern border of the Caribbean Sea. Its cone descends by steep slopes to the sea on all sides but the south, where it is bordered by a plain on which, before the eruption stood the city of St. Pierre, with a population of about 26,000. The crater of Pelée was half a mile in diameter, and its floor 2,000 feet below the highest part of the crater rim. This rim is broken at the southwest by a deep gash, or valley.

Before 1902, Pelée had had two periods of moderate activity within historic times, one in 1762 and the other in 1851, but neither was destructive to life. From 1851 to 1902 the volcano slumbered. In April, 1902, activity was renewed, by (1) the discharge of steam, vapors, and ashes, some of which were thrown 1,300 feet above the top of the mountain, and (2) by the opening of three vents in the basin of the old crater. By April 25th, the poisonous, sulphurous vapors issuing from the mountain had become so abundant that horses dropped dead in the streets of St. Pierre, and a little later the traffic of the streets was obstructed by the volcanic dust or "ashes." On May 5th the mud which had accumulated in the basin of the crater broke out and flowed down a valley in the side of the mountain, overwhelming a factory and destroying a number of lives. During these early stages of activity there were numerous earthquakes, and all cables from Martinique were broken, while sounds like the report of artillery were heard 300 miles away.

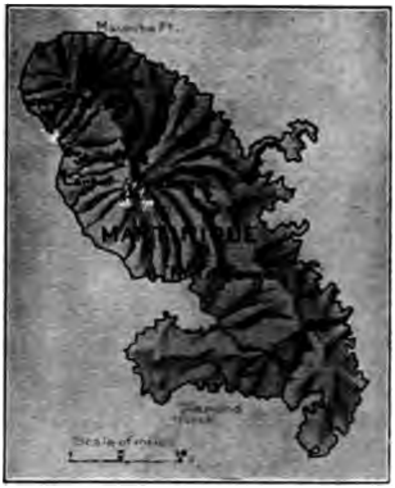

Fig. 284.—Sketch-map of Martinique. (Nat. Geog. Mag.)

On May 8th the activity of the volcano reached its climax. On that day a heavy black cloud swept down through the gash in the crater's rim, and out over the plain to the southwest, and in two minutes struck the city of St. Pierre, five miles distant. The city was at once demolished. Buildings were thrown down, statues hurled from their pedestals, and trees torn up. Explosions were heard in the city as the cloud reached it, and flames burst out, started either by the heat of the gases, or the red-hot particles of rock which the gases carried. A few minutes later a deluge of rain, mud, and stones fell, continuing the destruction. With but two exceptions, the entire population, increased to some 30,000 by refugees from the surrounding country, was wiped out of existence (Fig. 285). Of the two persons who escaped, one was in a prison cell below the level of the ground, while the other was in a house in the outskirts of the city. Many people on ocean vessels in the vicinity of St. Pierre were killed, some of them instantly. Others were seriously burned.

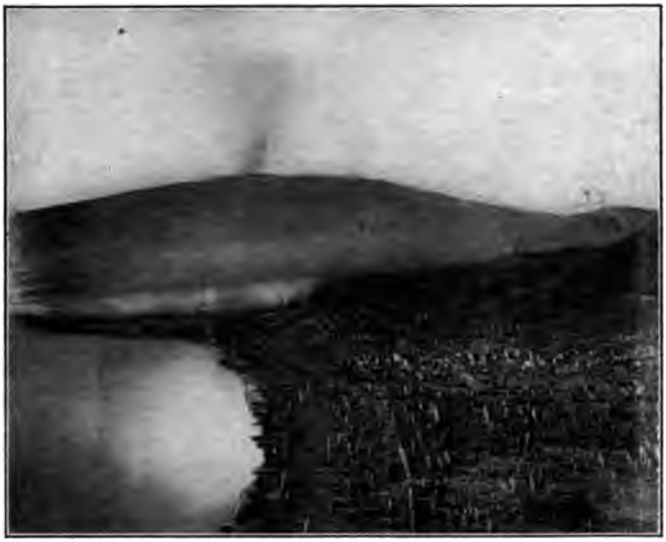

Fig. 285.—St. Pierre after the eruption of Mt. Pelée, which is seen in the distance. (Am. Mus. Nat. Hist.)

Study of the region after the eruption showed that the cloud was probably composed of steam, sulphurous vapors, and dust. It is estimated to have had a temperature of 1,400° to 1,500° F. (about 800° C.). Combustible gases seem not to have been abundant, for the vegetation and thatched roofs in the path of the blast were not burned, but only dried and withered. The bodies of the victims were scorched, burned, or scalded. Except in the axis of the blast, the clothing of the bodies was unburned, though the flesh beneath was burned and scalded. The chief causes of death seemed to have been suffocation by the noxious vapors and gases, and the great heat. Other causes of death were blows from stones thrown from the volcano, burns from hot stones, dust, and steam, cremation in burning buildings, etc.

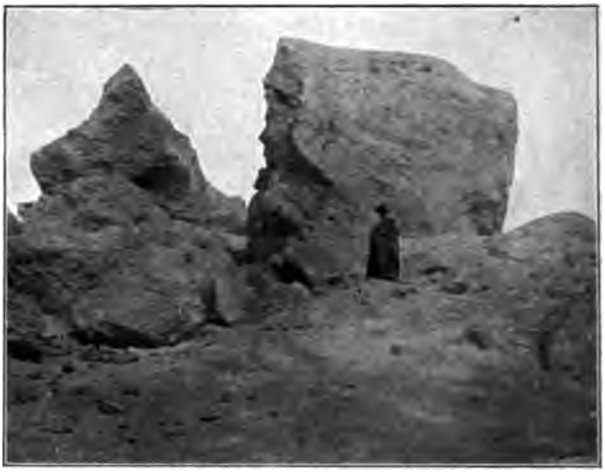

Fig. 286.—Great rocks thrown out by the eruption of August 30, 1902. (Am. Mus. Nat. Hist.)

Other eruptions occurred on May 20th, 26th, June 6th, July 9th, and August 30th. The blast of August 30th took a path somewhat different from that of the earlier ones, and devastated a number of villages in the vicinity of St. Pierre, adding about 2,000 to the list of human victims. Clouds of steam and ashes were thrown to heights of 6 and 7 miles.

An interesting case of sympathetic action was shown by a volcano (Soufrière) on the island of St. Vincent (Fig. 287), about 90 miles south of Martinique. After two days of warning symptoms, the first eruption of the Soufrière occurred on May 7th. The eruption was similar to that of Pelée, but as there was no considerable city in the path of the steam-cloud, the loss of life was much smaller, about 1,350. The discharges from the vent were not confined and directed by a valley, as were those of Mont Pelée, but spread over a larger area, with less violence. Later eruptions occurred on May 18th, and September 3d.

There were no lava-flows in connection with any of these eruptions of Pelée or the Soufrière. The dust discharged during these eruptions was carried long distances, and on St. Vincent it was 50 and 60 feet thick in some places, after the eruption was over.

Earthquake tremors felt in China on May 8th are supposed to have been connected with the violent eruption of that date. This is the only case, with the exception of Krakatoa, in which tremors are

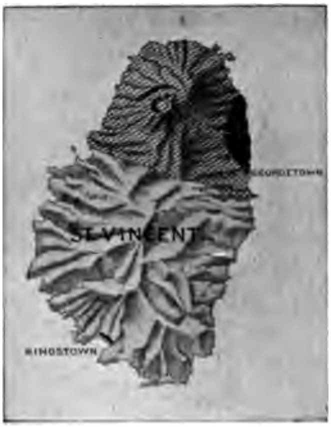

Fig. 287.—Sketch-map of the Island of St. Vincent, showing the zones of destruction. In the black area the destruction of life was nearly complete, in the shaded area (checked) slight.

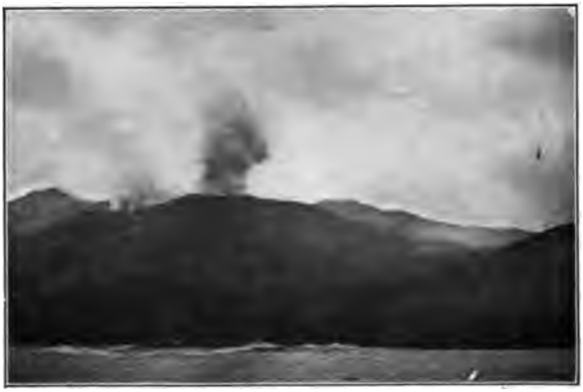

Fig. 288.—The Soufrière in eruption. Ruins of Walliban sugar-factory in the foreground. (Photograph by Wilson.)

known to have been transmitted through the center of the earth to the opposite side. Earthquake shocks were felt in Venezuela on August 30th.

Hawaiian volcanoes. The eruptions of the volcanoes thus far described are more or less violent; but in the Hawaiian Islands there are volcanoes whose eruptions are relatively quiet. Mauna Loa is the largest of the four volcanic cones whose united mass forms the island of Hawaii (Fig. 289), an island 80 miles across.

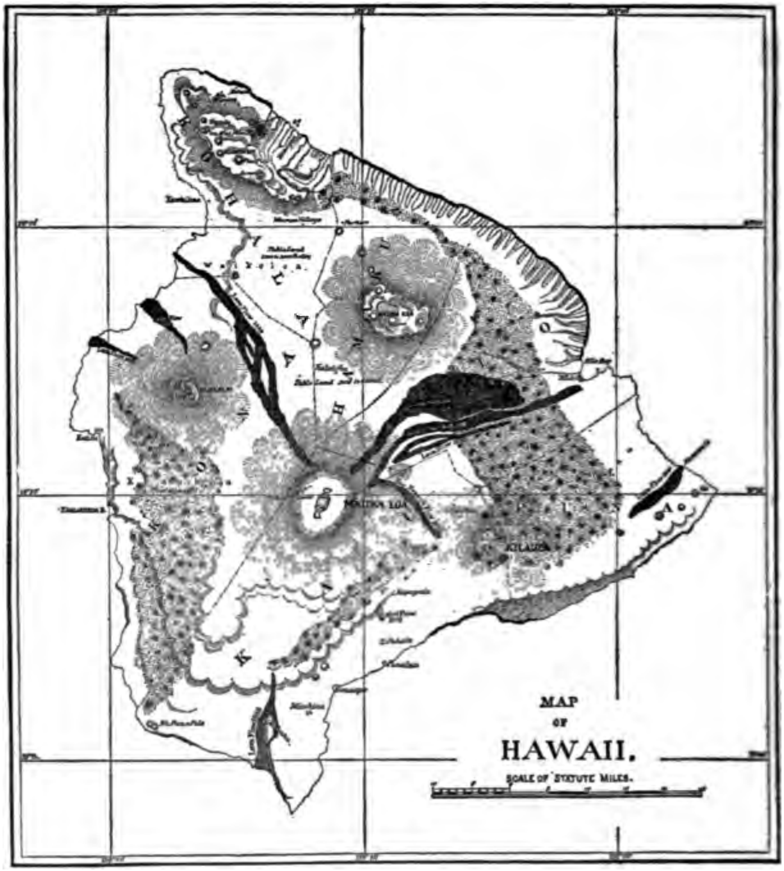

Fig. 289.—Map of Hawaii. (U. S. Geol. Surv.)

Mauna Loa rises 14,000 feet above the sea, but the island is built up from the sea bottom where the water is about 16,000 feet deep, so that the great volcanic pile, whose top is the island, is really about 30,000 feet high.

The crater of Mauna Loa is 3 miles long, 2 miles wide, and about 1,000 feet deep,— a very large crater. When the volcano is not active, it is possible to go down into the crater and to walk about on its hard, hot floor. Cracks and other openings are, however, generally present, and give evidence of the hot liquid rock beneath.

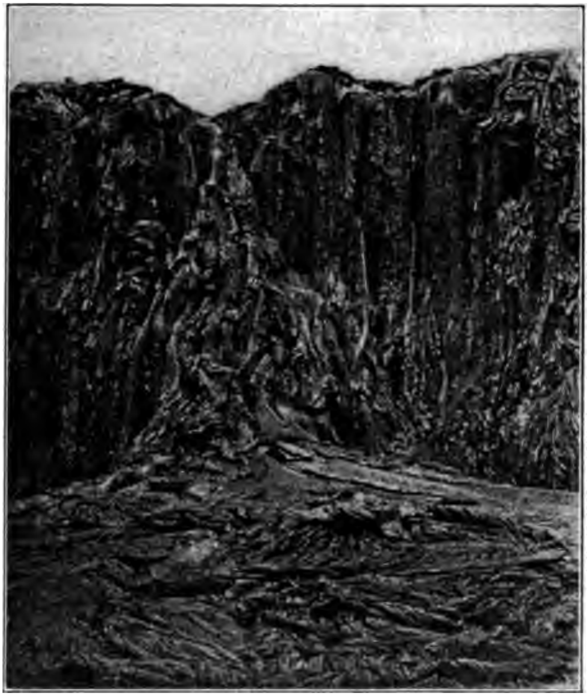

Fig. 290.—Lava falling over cliffs, Kilauea. (H. M. S. Challenger Rept.)

Before an eruption, the floor of the crater rises, and lakes of lava appear in the enlarged openings in it. At intervals, fountains of lava may rise from the lakes, sometimes to heights of several hundred feet. Finally the eruption occurs; but the lava does not usually flow over the rim of the crater. It generally comes out through cracks which open on the side of the mountain, sometimes far from the top. Through them the liquid lava spouts, sometimes high into the air, and then flows down the sides of the mountain in streams. Such streams may be half a mile in width, and some of them flow for 50 miles, with forms somewhat like those of mountain glaciers. Their rate of advance is, however, much faster than that of glaciers, though much slower than that of rivers. The flow becomes slower as the lava cools and stiffens. As the streams reach flatter ground, they spread out, and the lava may collect in hollows, forming pools and lakes, which soon harden. The lava occasionally falls over cliffs (Fig. 290), sometimes into the sea.

After it becomes hard, the surface of a lava-flow may be nearly smooth (Fig. 291), but it is often rough. It may be ropy (Fig. 292), due to movement of the lava after it is partially hardened.

During the eruptions of the Hawaiian volcanoes, little steam is discharged, and there are no showers of dust or cinders, no loud rumbling or explosive reports, and earthquakes are rare. The eruptions may continue for months at a time, with so little disturbance that only persons in the vicinity are aware of their existence.

Hawaii is one of a chain of volcanic islands, 400 miles long. Mauna Loa, therefore, like the other volcanoes studied, is one of a considerable number in its region.

Common phenomena of an eruption. From the preceding descriptions the essential features of eruptions may be gleaned. In the *explosive type* of eruption, rumblings and earthquake shocks, due to explosions within the throat of the volcano, often occur for weeks or months previous to a violent outbreak. As the explosions become violent, ashes, cinders, and bombs are shot forth and fall upon the sides of the cone, while the summit of the mountain is shaken. The clouds of condensed steam and dust rising from the crater darken the sky (Fig. 279), and torrents of rain, falling upon the fine dust, form rivers of hot mud. Liquid lava may or may not accompany the discharge of dust, cinders, etc. In the *quiet type*

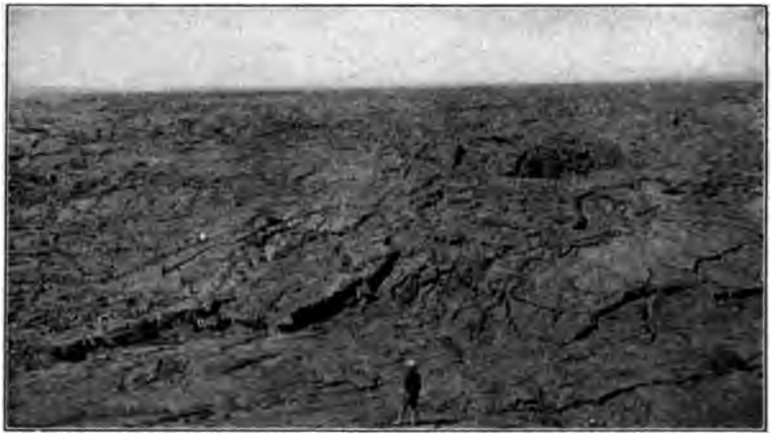

Fig. 291.—Relatively smooth lava surface near the Jordan Craters, Malheur Co., Ore. (U. S. Geol. Surv.)

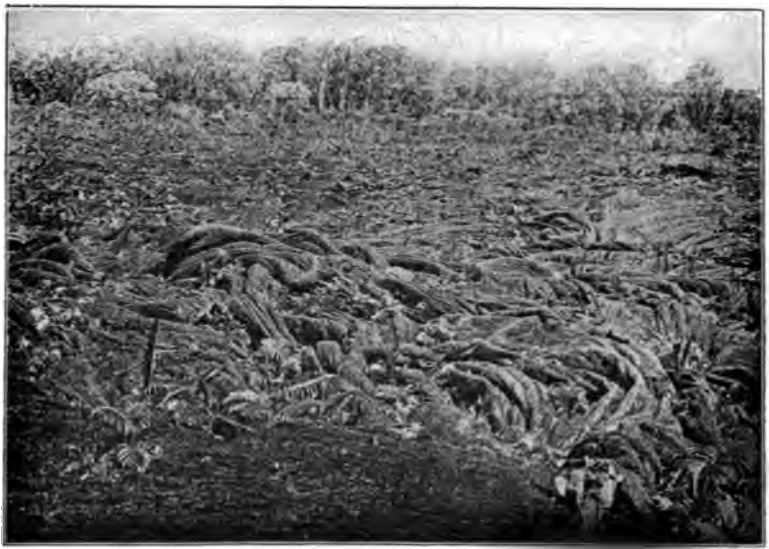

Fig. 292.—Ropy surface of lava, Mauna Loa, flow of 18[illegible] lvin.)

of eruption the lava rises in the crater and occasionally overflows its rim; but more commonly it breaks out through cracks in the side of the cone, so that the lava issues below the top.

There is little or no burning in a volcano, for there is little or nothing to burn. There is, therefore, no smoke. What appears as smoke is mostly condensed water vapor (cloud), often blackened by the dust.

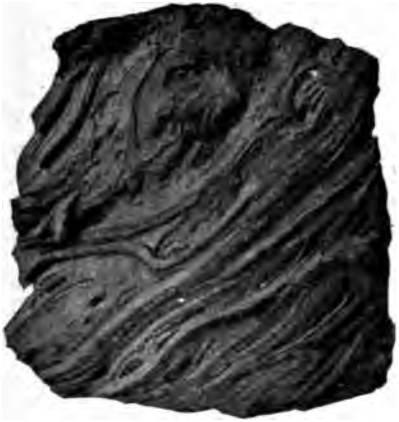

Fig. 293.—A bit of lava nearly natural size, showing a blistered surface. From Cinder Buttes, Idaho. (U. S. Geol. Surv.)

The Products of Volcanoes

As already stated, the materials which come out of volcanoes are partly solid, partly liquid, and partly gaseous.

Lava. This term is applied both to the liquid rock which issues from a volcano and to the solid rock which results from its cooling.

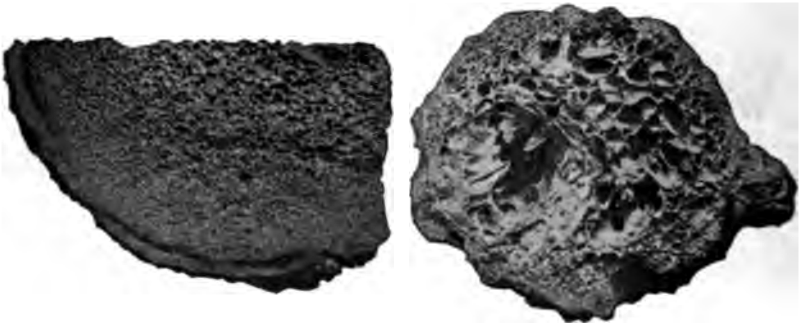

Fig. 294.—Scoriaceous lava. The little cavities are of the general nature of bubbles. They were filled with gas when the lava hardened. Cinder Buttes, Idaho. (U. S. Geol. Surv.)

Lava never flows so freely as water, and it is sometimes very stiff or viscous. The distance to which it flows depends on its amount, on the slope of the surface over which it flows, and on its liquidity. The greater the amount of lava, the steeper the slope, and the more fluid it is, the farther it will flow.

Lava takes on various forms as it becomes solid. If it hardens under little pressure, as at the surface, the gases and vapors which it contains may expand, and it is converted into a sort of rock froth (Fig. 294). If the lava solidifies quickly, without becoming frothy, it makes *volcanic glass*, or *obsidian*. If the lava cools slowly under pressure, the substances of which it is composed crystallize into the form of various minerals. The kinds and proportions of the minerals depend upon the composition of the lava.

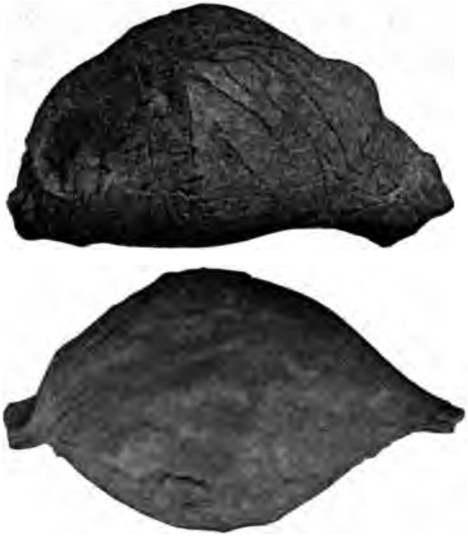

Fig. 295.—Volcanic bombs. Masses of lava of these and other similar shapes are sometimes thrown from volcanoes, and are known as bombs. The bombs may be from a few inches to a few feet in diameter. Cinder Buttes, Idaho. (U. S. Geol. Surv.)

Cinders, ashes, etc. Most of the fragmental materials blown out of a volcano are pieces of lava which solidified before they were blown out, or during their flight in the air. Tl masses of rock tons in weight, and smaller pieces of all sizes down to minute particles of dust or "ash." It should be noted, however, that "volcanic ash" is not ash in any proper sense of the term, for it is not a product of burning. The dust is often shot up high into the air, and, being light, is caught by the winds and scattered broadcast, some of it coming to rest thousands of miles from its starting-point (p. 28). The fluid lava, and the larger fragmental materials, on the other hand, stay near the vent.

Gases and vapors. The gases and vapors which issue from volcanoes are of many kinds. Some of the commoner ones are water, carbonic-acid gas, chlorine, hydrochloric acid, sulphur dioxide, and sulphide of hydrogen; but with these more important ones there are many others. Some of the gases are poisonous, and, as in the case of Pelée, their temperature is sometimes so high as to be destructive to life.

Number, Distribution, etc.

Number. The number of volcanoes is not easily determined, and is not definitely known. There are various reasons for this uncertainty. Thus it is often impossible to say whether a quiet volcano is dormant or extinct. If the former, it should be counted; if the latter, it should not. Again, the discharge of lava sometimes takes place from several small vents in or about a single volcanic cone. In such cases there may be difference of opinion as to whether the several vents should be regarded as separate volcanoes. For these and other reasons, the number of active volcanoes cannot be stated exactly, but it is commonly estimated as between 300 and 400. Something like two-thirds of them are on islands, and the remainder on the continents. There may be others in the sea which are not known, for feeble volcanoes in the deep sea would make little show at the surface.

Distribution. The general distribution of active volcanoes is shown in Fig. 296. Many of them are arranged in belts, within which they are sometimes in lines. The most marked belt nearly encircles the Pacific Ocean, as with a girdle of steaming vents. This belt may be said to begin with the volcanic islands south of South America, and includes the numerous vents in the Andes, and

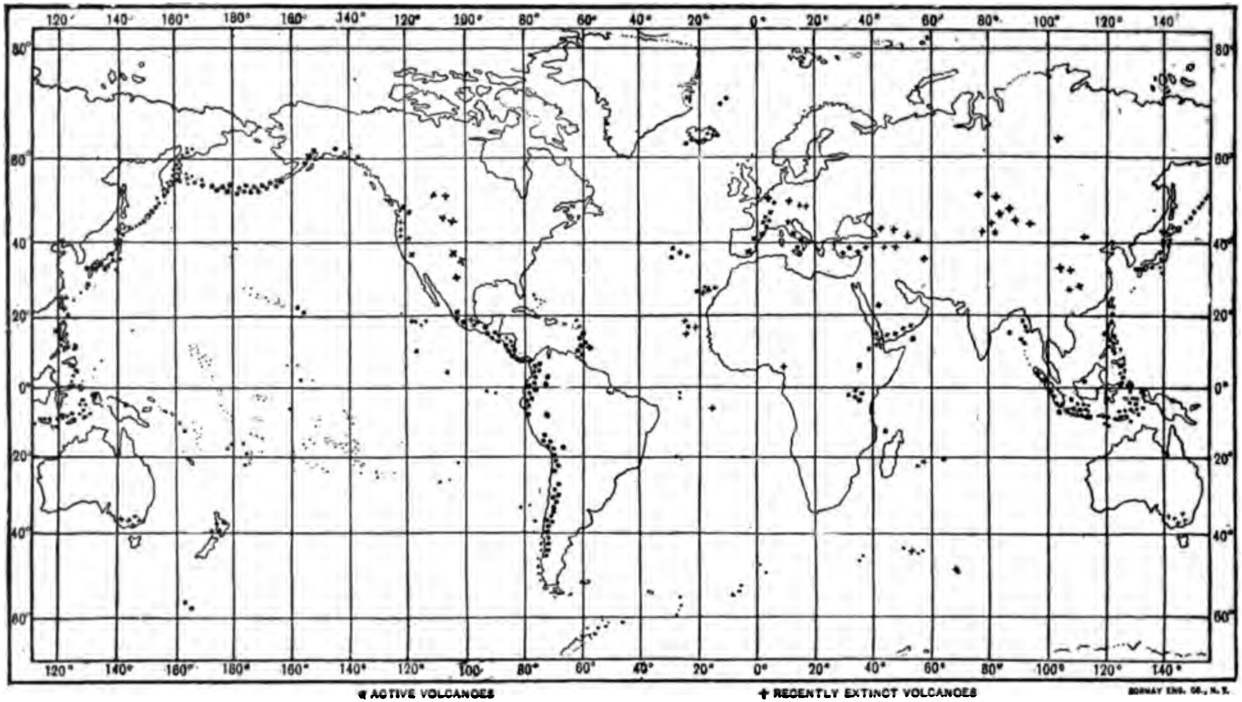

Fig. 296.—Map showing the distribution of volcanoes. (Russell.)

in the mountains of Central America and Mexico. It widens in the western part of the United States, where the volcanoes are extinct, but narrows again in Alaska and the Aleutian Islands. On the western side of the Pacific, the belt includes the many active vents of Kamchatka, Corea, Japan, the Philippine Islands, New Guinea, New Hebrides, and New Zealand, and an off-shoot from it includes the volcanoes in the islands of Java and Sumatra. The volcanoes of the West Indies are sometimes considered as an eastern branch of the same belt. Outside this belt, volcanoes are numerous in and about the Mediterranean Sea, and there are many others which cannot be connected with any well-marked system.

Most volcanoes are in the sea or near it. Not a few of them are in mountain regions, though they do not occur in all mountains. Many are on ridges or swells on the sea bottom, or on ridges or swells which rise above the sea. Such, for example, are the West Indian volcanoes. The volcanoes on the continents are mostly near the shores, but many shore lands are without them, and there are a few volcanoes far from the sea. Thus there is an active volcano in Africa 700 miles from the sea, and there are fresh cones of extinct volcanoes 500 to 800 miles from the sea in Arizona, Colorado and elsewhere. It cannot be said, therefore, that nearness to the sea or mountain ridges are conditions necessary for volcanoes.

Many of the active volcanoes lie near the line where the continental plateau descends to the oceanic basins. This is perhaps the most significant feature of their distribution.

From the data now known, it would appear that volcanoes on land are commonly associated with lands which have been recently raised or sunk. It may be that movements of the crust of the earth have some effect upon the pressures and temperatures of the deeper zones beneath them, and these variations of pressure and temperature may be among the conditions necessary for the eruption of lava.

Historical. Volcanoes have existed throughout the history of the earth, so far as this history is now known, even back to the earliest ages; but volcanoes do not seem to have been equally ve at all times. There have been periods of great volcanic activity, alternating with periods of less activity. There is no knowledge, however, that vulcanism ever ceased altogether at any time.

While volcanoes seem to have existed, periodically at least, throughout all that part of the earth's history which is known, the sites of volcanoes have shifted from time to time, so that the areas where they now exist are not the areas where they existed in former times.

Even after the volcanoes of a region die out, associated phenomena are sometimes continued. Thus in the Yellowstone National Park, where volcanoes once existed, there are numerous geysers, hot springs, and other vents out of which hot vapors issue. These phenomena perhaps represent the last phases of volcanic activity in the region.

Topographic Effects of Volcanoes

By the making of cones, volcanoes become an important factor in shaping the surface of the lithosphere. The early stages of growth have sometimes been observed. Thus in 1538 a small volcano appeared on the north shore of the Bay of Naples, and built up a cone 440 feet high and half a mile in diameter at its base in a few days. Its crater was more than 400 feet deep. The development of the volcano was preceded by earthquakes which were felt in the same region for two years or more before the volcano appeared.

In 1770 the volcano Izalco in Central America broke out in the midst of a plain which was then a cattle-ranch. Since that time it has built up a cone about 3,000 feet high, with steep slopes. In the earlier part of its history, lava-flows were frequent, but for many years no lava has flowed out, though the volcano has remained active, discharging explosively. Earthquakes and rumblings preceded the original eruption.

Early in the last century a volcanic island (Graham Island) arose in the Mediterranean, between Sicily and Africa, where the water had been 800 feet deep. In 1831 a ship near the place felt earthquake shocks. In July a sea captain reported that he saw a column of water 60 feet high and 800 yards in diameter rising

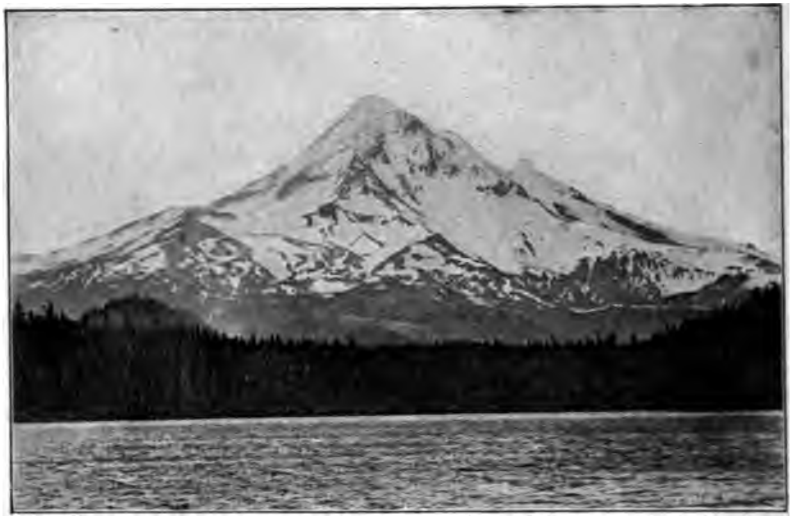

Fig. 297.—Mt. Hood, a snow-capped mountain. (By permission of Lipman, Wolfe & Co.)

Fig. 298.—Orizaba, Mexico, 18,240 feet high. (Chamberlin.)

from the sea, and soon afterward a column of steam which rose 1,800 feet. A few days later there was a small island 12 feet high where the disturbance had been, and in its center there was a crater, from which eruptions were seen to be taking place. By the end of the month the island was 50 to 90 feet high, and three-fourths of a mile in circumference, and on August 4th it was 600 feet high, and 3 miles in circumference. Activity soon ceased, and early in 1832 the island had been destroyed by the waves. This volcano was short-lived, as was the island which it built.

Volcanoes have recently built up islands off the coast of Alaska. In 1795 such an island appeared about 40 miles west of Unalaska. In 1872 this island was 850 feet above the sea, but had no crater. In 1883 another island appeared close by, and was later joined to the first. In 1884 it was 500 to 800 feet high. Another volcanic cone was first seen in 1906, when it appeared as a great steaming dome, and was named Parry Island.

Some volcanic cones make mountains of great size. Such are Mt. Rainier (Fig. 303) in Washington, Mt. Hood in Oregon (Fig. 297), Mt. Shasta in California, Orizaba in Mexico (Fig. 298), and many others. All of those named above are so high that, in spite of the great heat connected with their origin, snow-fields and glaciers are found upon their slopes. The number of volcanic cones is far greater than the number of volcanoes, for the cones of many extinct volcanoes still remain.

Many small islands, and some large ones, such as Iceland, are due chiefly or wholly to the building up of volcanic cones which have their foundations on the ocean bottom. The Aleutian Islands, the Kurile Islands, and many of the islands of Australasia are examples of islands formed in the same way. In spite of their great number, the aggregate area of volcanic cones is relatively slight, and the total area of mountainous land developed by volcanoes is but a fraction of the area of mountain land developed in other ways. It is to be especially noted that volcanoes do not make great mountain ranges, though they make great single mountains.

Destruction of volcanic cones. Volcanic mountains, like all other elevations on the land, are subject to change and destruction. They may be partially destroyed by violent explosions, as in the

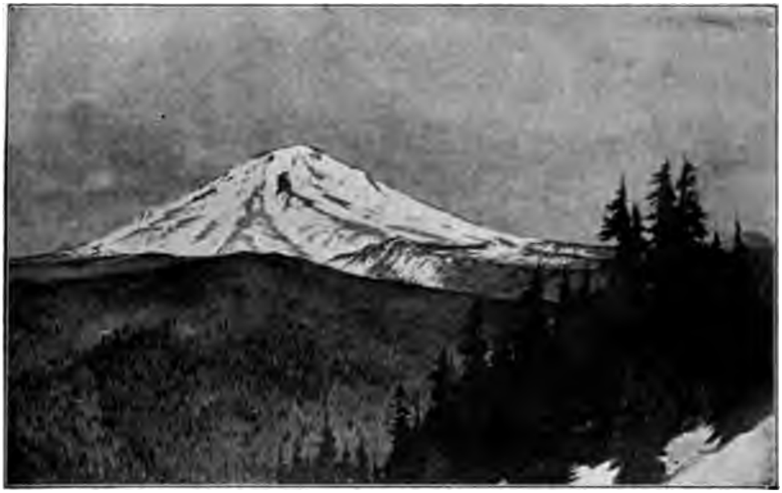

Fig. 299.—Mount Mazama (the name given to the former mountain where Crater Lake now is), as it is conceived to have been before the collapse which formed the lake basin. (U. S. Geol. Surv.)

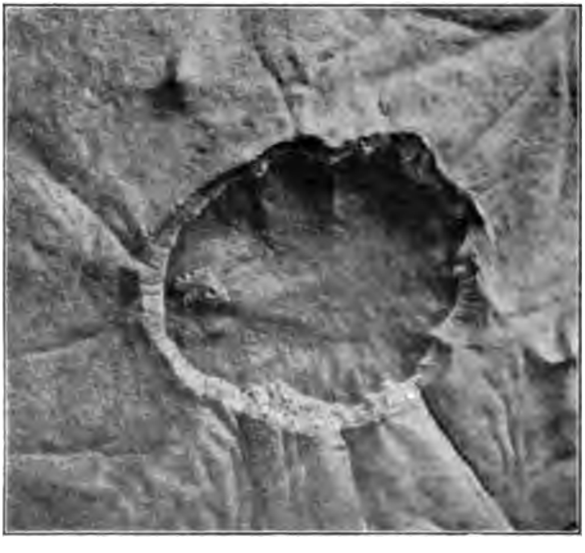

Fig. 300.—The rim of Crater Lake. (U. S. Geol. Surv.)

cases of Krakatoa and Vesuvius, already cited. Again, the entire summit of a volcanic mountain may sink, leaving a great depression, or *caldera*, where it was. Crater Lake, Oregon, occupies a wonderful caldera five or six miles in diameter, and 4,000 feet deep, in the stump of a great volcanic cone (Figs. 299 and 300). The lake, the remarkable dimensions of which have been given (p. 216), is surrounded by nearly vertical walls of rock 900 to 2,200 feet high. Since the sinking in of the top, a small cone, which now rises as an island in the lake, has been built up.

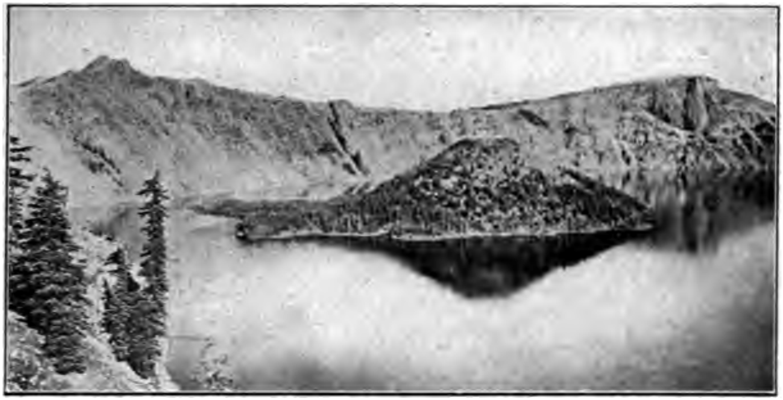

Fig. 301.—Western border of Crater Lake. (U. S. Geol. Surv.)

It is not easy to see why the whole top of a great mountain should sink so as to leave such a great basin. Perhaps it was undermined by the flow of the lava beneath to some other place.

Volcanic cones are also destroyed by the slow processes of weathering and erosion. Wind and rain attack volcanic cones as soon as they are formed, but their results are not conspicuous until the volcano is extinct and the cone stops growing. Cones composed largely of cinders, etc., are worn away with comparative ease, while those of lava are more resistant. Glaciers frequently aid in their degradation. Among the many extinct volcanic peaks in the western part of the United States, it is possible to find illustrations of cones in various stages of destruction. Only those of recent origin still show their original forms, or forms but slightly modified. None but recent cones retain their craters, or the symmetrical slopes they once possessed.

Volcanic cones in the sea or in lakes are attacked by waves as well as by running water, and small cones in the sea are soon worn away. The case of Graham Island is an example.

Examples of fresh cones. In Arizona, California (Fig. 302), Idaho, Oregon, and elsewhere in the United States there are volcanic cones so recently formed that they have suffered but little erosion. Cones of similar freshness are found in other lands.

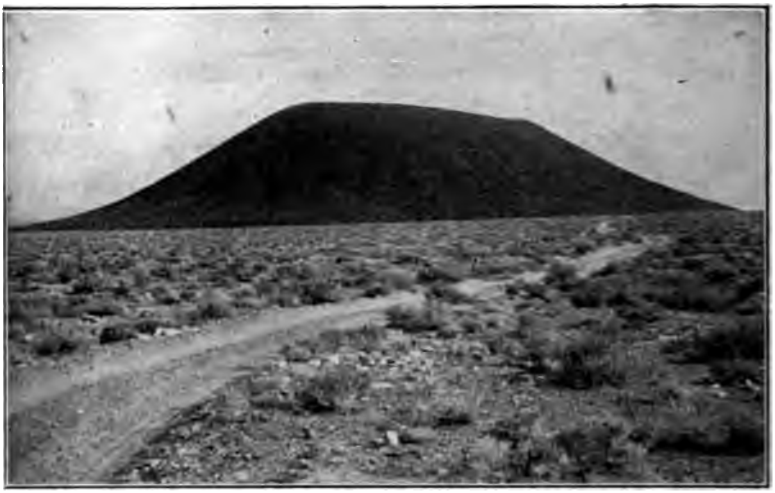

Fig. 302.—Typical cinder cone, Clayton Valley, Cal. (U. S. Geol. Surv.)

Examples of worn cones. *Mt. Shasta* rises two miles above a base seventeen miles in diameter, to a height of 14,350 feet above the sea. It is partly of lava and partly of fragmental material. Its upper slopes are steep and furrowed with ravines. About 2,000 feet below the summit on the west side is a fresher and therefore younger cone (Shastina) with a crater in its top. Remains of more than 20 smaller cones also occur on the lower flanks of the main mountain. Mt. Shasta is a good example of a volcano which has suffered some erosion, but there is still abundant evidence of rather recent eruptions.

Mt. Rainier (Fig. 303) is another splendid mountain developed by a former volcano. Various features of the mountain show that a second period of activity followed a long period of quiet in the history of this snow-capped mountain. Hot vapors still issue from some small vents in the mountain, though the discharge of rock material ceased long ago. The mountain is snow-covered, and has several glaciers.

The Marysville buttes. This circular cluster of hills (Fig. 304), 10 miles in diameter, rises 1,700 to 2,000 feet above the level of the Sacramento River in California. The buttes are composed of lava with an outer layer of fragmental material (or tuff). The volcanic cone, which probably once rivaled Vesuvius, has been dissected into a group of hills with jagged and fantastic outlines. So deeply have the roots of the mountain been laid bare, that the broken and distorted layers of sedimentary rock through which the lava was erupted are exposed.

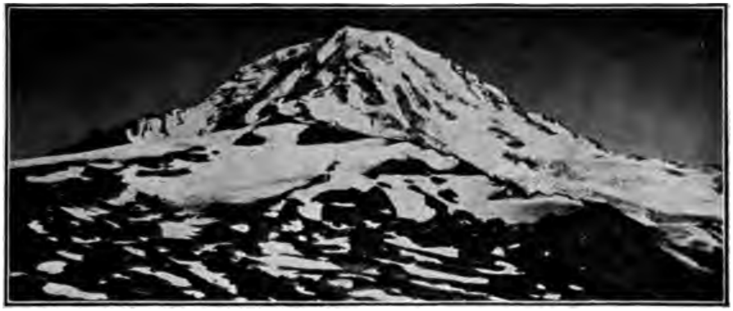

Fig. 303.—The summit of Mount Rainier, Washington. (By permission of W. P. Romans.)

Volcanic necks. When a volcano becomes extinct, the throat, or passage from the interior, may be filled with hardened lava. This may be of rock much more resistant than the rest of the cone, and as the cone is worn away, the *plug*, transformed into a hill, may still mark the site of the former volcano. These volcanic *necks*, or *plugs*, are sometimes conspicuous. East of the Mt. Taylor plateau, in central New Mexico, a number of them rise by precipitous slopes 800 to 1,500 feet above their surroundings. Massive intrusions of lava may have a similar effect (Fig. 129).

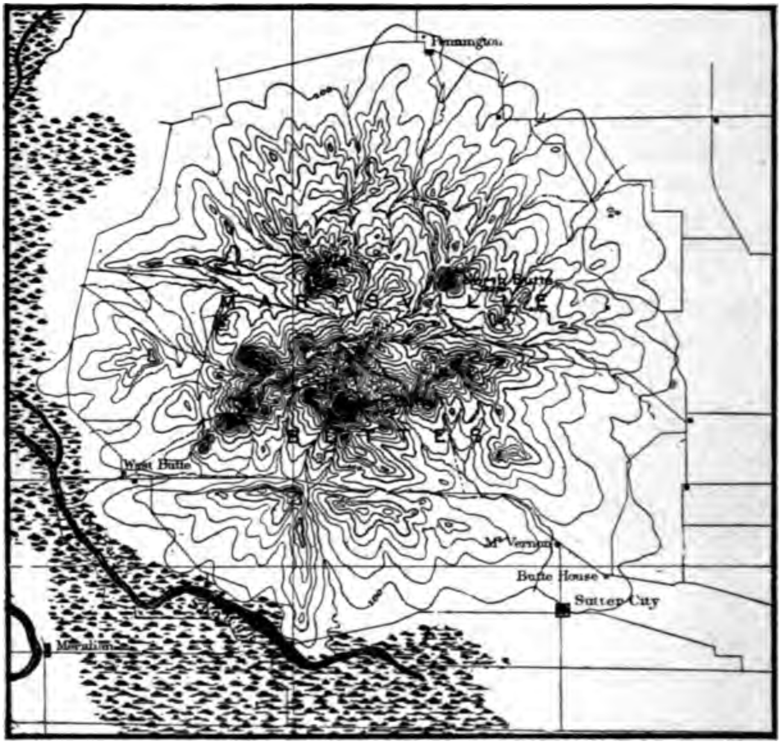

Fig. 304.—Marysville buttes in contour. (U. S. Geol. Surv.)

Mud Volcanoes

Mud volcanoes have some features in common with volcanoes and some in common with geysers, while in other respects they are unlike both. Like volcanoes and geysers, they are eruptive, but, as the name implies, their discharge is mud, instead of lava or water. The conditions which cause them seem to be (1) sufficient heat beneath the surface, probably at a slight depth, to produce steam, (2) the absence of an open tube through which the steam may escape, and (3) a surface layer of earthy material, which, when moist, becomes mud. The steam escaping through the mud forces some of it out, building up small cones (Fig. 305), which are somewhat like volcanic cones in form, though not in constitution. They never reach great size.

Like geysers, mud volcanoes occur in regions of present or recent vulcanism. They are sometimes violently explosive, and sometimes not. Some of them erupt at infrequent intervals, and some nearly continuously.

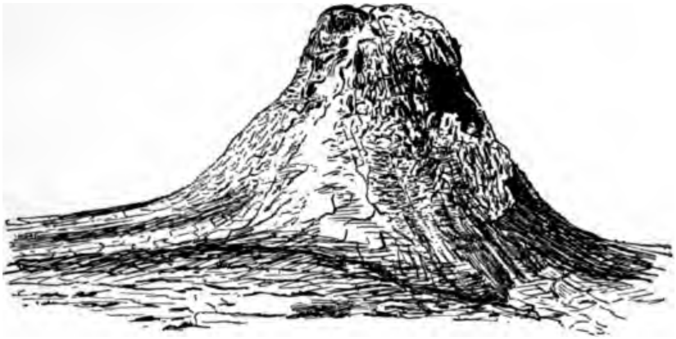

Fig. 305.—Mud volcano, a few feet high. The Colorado Desert.

Fig. 306.—An island formed by a mud volcano, December, 1906, near the head of the Bay of Bengal. The sketch represents the island as seen from a distance of about half a mile. (Headlam.)

Examples of mud volcanoes are known at various points in the western part of the United States. Some of the finest examples are in the Colorado Desert of southern California, but they occur also at other points.

In December, 1906, a mud volcano built a cone near the coast of Burma, at the head of the Bay of Bengal (Fig. 306). The water about the volcano had a depth of about 60 feet, and the cone was built up until it became an island 19 feet high.[1]

IGNEOUS PHENOMENA NOT STRICTLY VOLCANIC

Fissure eruptions. Lava sometimes rises to the surface through great fissures instead of through the relatively small vents of volcanoes. From such fissures floods of lava spread over the surrounding country for hundreds of miles. Such lava floods once occurred in Oregon, Washington, and Idaho, where by successive flows, the former hills and valleys were buried, and a vast plateau 200,000 square miles or more in extent was built up (Fig. 18). In some places, the nearly level surface of the lava plateau meets the mountains along its border, somewhat as the sea meets the land, while islands of older rock rise above it.

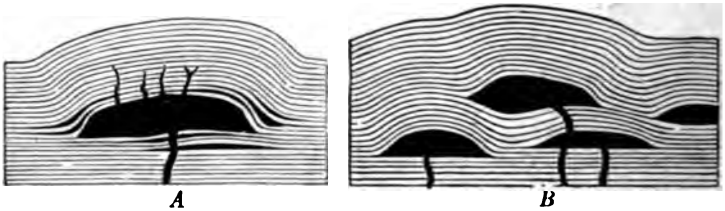

Fig. 307.—*A*. Ideal cross-section of a laccolith with accompanying sheet and dikes. *B*. Ideal cross-section of a group of laccoliths. (U. S. Geol. Surv.)

In this lava plateau, the Snake River has excavated a great canyon (Fig. 87) 4,000 feet deep in some places, and 15 miles wide. The walls of the canyon show the structure of the plateau. They show, among other things, the edges of the successive flows of lava, sometimes separated by beds of sediment, with soils in which the roots and trunks of trees are still preserved. These beds of sediment, and these soils, show that long periods of time elapsed between successive lava-flows.

An older lava plateau of still greater size occurs in India. Owing to its greater age, its nearness to the sea, and the humid climate, it is more dissected by erosion than the Oregon plateau.

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[1] Headlam, Geog. Jour., April, 1907.

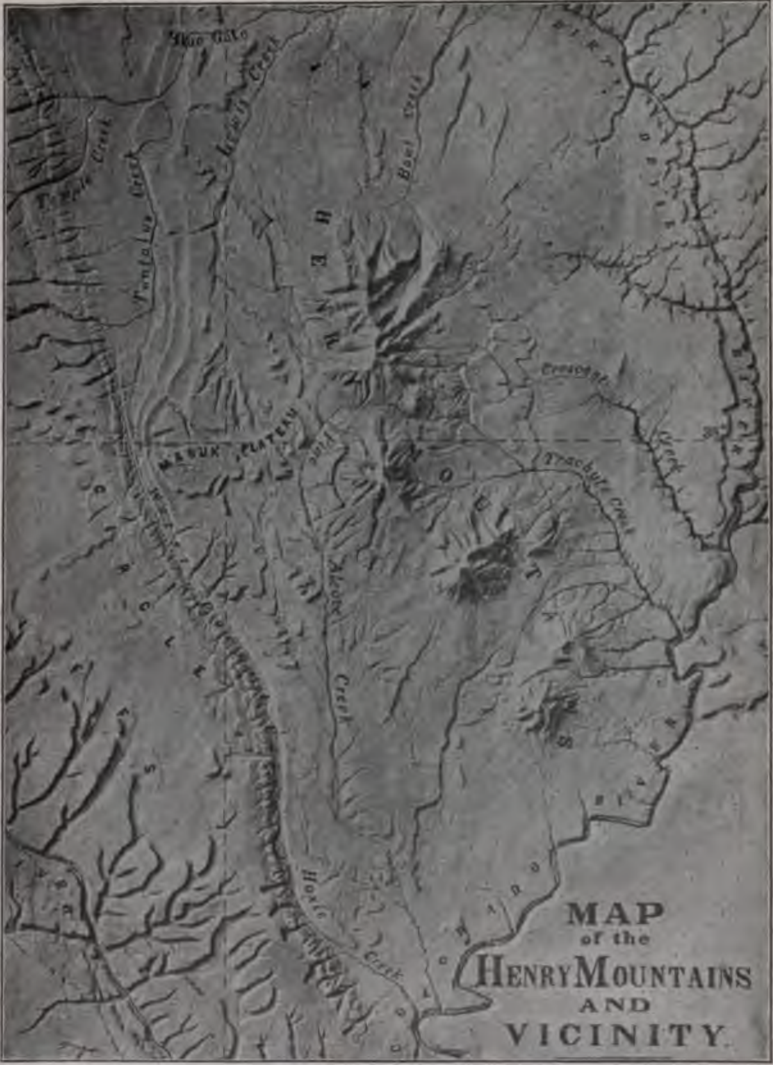

Fig. 308.—Relief-map of the Henry Mountains. These mountains are *laccoliths*, having the type of structure shown in Fig. 307. (U. S. Geol. Surv.)

Other lava plateaus, now made rough by erosion, are found on the north coast of Ireland and the west coast of Scotland, and some of the islands off Scotland are remnants of an old lava plateau.

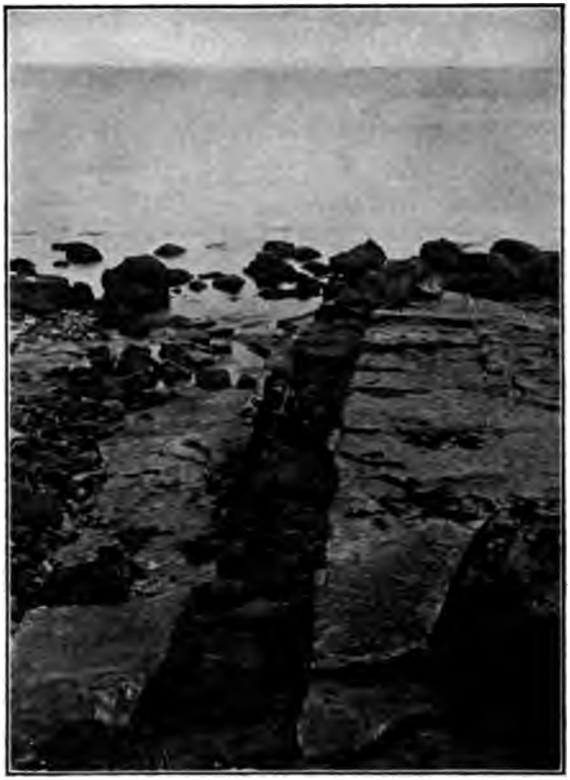

Fig. 309.—A dike two feet wide, cutting through sandstone. The photograph shows the dike as seen at the surface, on land scarcely above the water. Arran, coast of Scotland. (H. M. Geol. Surv.)

Fissure eruptions have occurred in Iceland within historic times. In 1783 such flows took place from a fissure 20 miles or so in length. The lava spread out in sheets on both sides of the fissure, advancing down the valleys farther than on the uplands between them. In this respect, the flow of lava resembles the movement of glacier ice.

While fissure eruptions of lava sometimes build up plateaus or raise the level of the plains on which they spread, they do not commonly give rise to mountains; but mountains are sometimes developed from them, as they are dissected by stream erosion.

Intrusions of lava. Lava is sometimes intruded from below into the crust of the lithosphere, without rising to the surface. In such cases the surface strata may be arched up over the intrusion, making domes which sometimes reach the size of mountains.

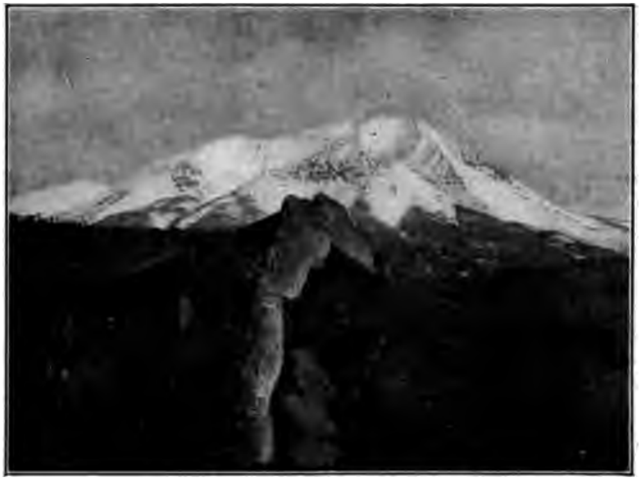

Fig. 310.—A dike isolated by erosion, Spanish Peaks region, Colo. (U. S. Geol. Surv.)

The Henry Mountains of Utah are examples (Figs. 307 and 308). The roof of the intrusion may be broken and lifted up, instead of being arched. Lava is sometimes forced in between beds of stratified rock in sheets, and into cracks of the rock, forming *dikes* (Figs. 309 and 310).

Intrusions of lava may give rise to topographic features of importance after erosion has affected the regions where they occur, for the hardened lava (or igneous rock) is often harder than its surroundings. Dikes often give rise to ridges (Fig. 310). Intruded sheets of lava also, if they have been tilted from a horizontal position, may give rise to ridges, and these ridges may be so high as to be called mountains. The Palisade Ridge of the Hudson (Fig. 202), and most of the mountains of the Connecticut River valley, are examples. Sills and extrusive sheets of lava may also give rise to buttes (p. 117), mesas (p. 118), rock terraces, etc.—indeed, to all the topographic forms which result from the erosion of rock of unequal hardness (p. 111 *et seq.*).

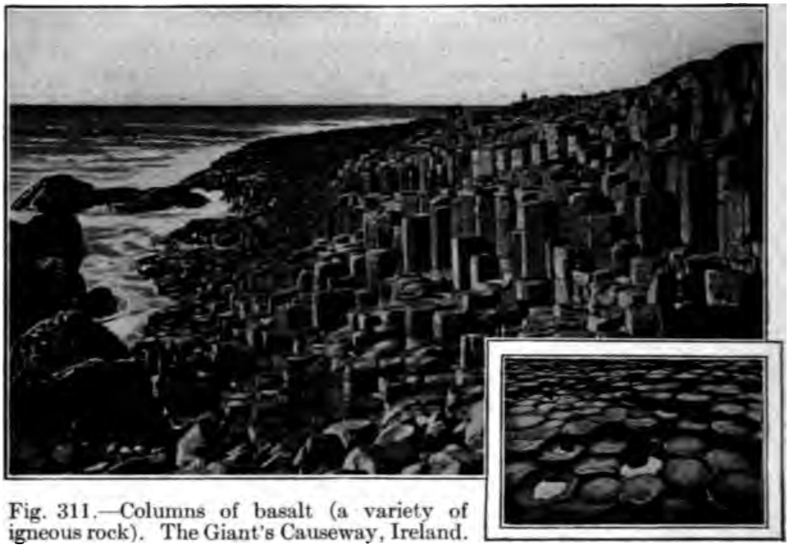

Fig. 311.—Columns of basalt (a variety of igneous rock). The Giant's Causeway, Ireland.

Columnar structure. As lava hardens it sometimes assumes a columnar structure (Fig. 311). This is probably the result of the contraction that goes with the cooling. The columns are mostly six-sided, as at Giant's Causeway, Ireland, along the Columbia River in Washington, and elsewhere.

Causes of Vulcanism

The causes of volcanoes lie outside the field of physiography, but it may be stated that the old notion that volcanic vents are connected with a liquid interior has been generally abandoned. Yet it seems clear that the interior of the earth is hot. Deep mines and deep borings of all sorts show that the temperature increases with increasing depth. The rate of increase varies from 1° F. for 17 feet in rare cases, to 1° for more than 100 feet. The average rate of increase is commonly stated as about 1° for every 50 to 60 feet; but if we take the records of those deep mines and other borings which seem most reliable, the rate is more nearly 1° for 100 feet, down to the greatest depths yet penetrated. It is to be remembered, however, that the deepest excavations are but little more than a mile in depth.

If the heat increases at the average rate of 1° for each 100 feet, a temperature of 3,000° would be reached at a depth of about 60 miles. Such a temperature would be enough to liquefy rocks *at the surface;* but it does not follow that they would be liquid at the depth of 60 miles at this temperature. At this depth, the pressure of the overlying rock is enormous, probably enough to keep the rock solid long after it reached a temperature which would make it liquid at the surface. Furthermore, there are other reasons for believing that, though the temperature of the interior of the earth is very high, the rock is still solid.

Among the vapors which escape from volcanoes, there are those which might have been derived from sea-water. From this fact it was formerly thought that sea-water had access to the sources of the lava. It is now believed, however, that water from the surface does not descend more than five or six miles (p. 47). It seems certain that the sources of the lava are much deeper, and it therefore seems improbable that descending water, either from the sea or from the land, reaches these sources.

Since lava is formed at depths and at temperatures which can not be studied, there are many points concerning its origin about which we cannot be sure. But it seems probable (1) that the lava is being formed all the time, in spots, in the deep interior, and (2) that it is all the time finding its way to the surface, but faster and in greater quantities at some times than at others. The regions where the crust is least stable, that is, where there is movement, are the regions most likely to afford the lava a place of escape.

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CHAPTER VIII

CRUSTAL MOVEMENTS

Though the crust of the earth seems to be firm and stable, it is in reality subject to frequent movements. Earthquakes are of rather common occurrence, and there is abundant evidence that other movements, too slow to be seen or felt, are going on all the time. Some of the proofs that such changes have taken place in recent times are the following:

Relative Rise of Coast Lands

1. Along some coasts, old docks near sea-level when they were built are found many feet above it, on dry land. This is the case, for example, at the west end of the island of Crete, in the Mediterranean Sea. Clearly the sea has sunk, or the land has risen, since the docks were built.

2. In the Baltic Sea there are rocks now above the water which within historic time were beneath the sea, though so near its surface as to be dangerous to navigation. The bottom of the shallow sea has risen, or the surface of the water has become lower.

3. Some animals in the sea attach themselves to the cliffs at sea-level or below it. Their shells or other hard parts sometimes remain long after the animals are dead. Among the animals which have this habit are barnacles, and their shells are sometimes found many feet above the surface of the water, attached to the rocks where they grew. They show that the land has risen relative to the sea since the animals lived.

The shells of marine animals are also sometimes found above sea-level, in sand, gravel, etc. Where such shells are in sediment which was deposited beneath the sea-water, they show that the sea bottom has become land since the animals lived in the shells.

It should be remembered, however, that birds and other animals frequently carry shells back from the coast, even to high lands. Before marine shells on land can be taken as proof of relative rise of the land, therefore, it must be certain that they were not carried inland.

Beds of sediment containing sea shells, certainly deposited beneath the sea in recent times, are now found above the water in many places, as in North Greenland, on the Pacific coast of the United States, in the West Indies, on the west coast of South America, and in northwestern Europe. In North Greenland very fresh shells are found in shore sand up to heights of 100 to 200 feet above the sea. We conclude that the sand in which they are found was beneath the sea but a short time ago. Darwin long ago found shells, etc., along the west coast of South America up to elevations of 1,300 feet above the sea. On the coast of Peru a coral reef is said to be found at an elevation of nearly 3,000 feet, and on the coast of New Hebrides and Cuba they are found up to heights of 1,000 feet or more.

4. Beaches, terraces (Fig. 268), and sea cliffs (p. 230) along the shore, but above the level of the sea, also show a rise of the land or a sinking of the sea. Such features are found along many coasts. In California and Scotland, some towns are built on elevated shore terraces, and wagon-roads and railroads follow them for considerable distances.

One of the significant facts concerning the elevated beaches, and other shore features, is that they are no longer horizontal, as they must have been when formed. They were warped as they rose above the sea, or as the sea sank below them.

All these phenomena are evidence that areas once covered by the sea have emerged in recent times. It is to be noted that the emergence of the land might be explained in either of two ways: (1) by the rise of the sea bottom, or (2) by the sinking of the sea-level.

Relative Sinking of Coastal Lands

1. At the east end of the island of Crete, ancient buildings are under water. On some parts of the coast of Greenland, too, various human structures built on land are now beneath the

water. The southern end of Scandinavia has been sinking recently, while the rest of the peninsula appears to have been rising. "At Malmö, one of the present streets is over-flooded by the waters of the Baltic when the wind is high, and excavations made some years ago disclosed an ancient street at a depth of eight feet below the present one."

2. Along some coasts there are drowned forests. Thus north of Liverpool, England, when the tide is out, numerous stumps may be seen standing on the beach where the trees once grew (Fig. 312). Since trees of the kind represented by these stumps do not grow in salt water, we conclude that the land where they grew has sunk below the level of high water. On the coast of New Jersey, too, stumps are known to exist several feet below sea-level.

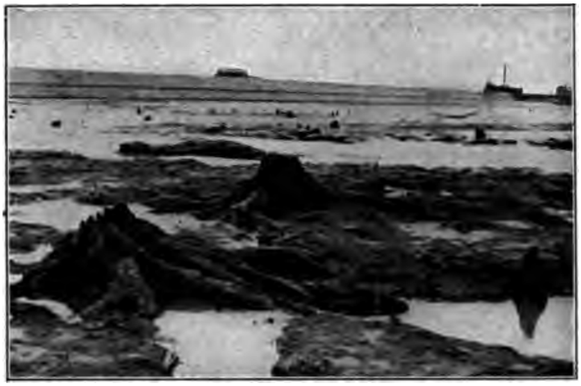

Fig. 312.—Stumps laid bare on the beach at low tide. Leasowe, Cheshire, Eng. (Ward.)

3. Some river valleys on land, such as the Hudson (Fig. 313), the Delaware, and others, are continuous with valleys in the shallow sea bottom far out beyond the coast-line. Such submerged valleys indicate that the surface where they are was land when they were made, and that they have been sunk beneath the sea. The many bays on the eastern coast of the United States, especially between New York and Carolina, show recent sinking of the land, enough to carry the lower ends of the former valleys below sea-

level, thus changing them into bays. Drowned valleys (p. 119) of this sort are found in many parts of the earth, and show that coastal lands have sunk recently along many coasts.

All these cases of apparent sinking of the land might be explained by the rise of the sea instead.

4. One of the most striking cases of change of level appears to involve both upward and downward movement. On the shore of Italy, near Naples, are the ruins of an old temple (Fig. 315). It is known to have been above water as late as 235 A. D. In 1749 several columns of the temple were found. Their bases were buried to a depth of 12 feet in sediment deposited by the sea. For 9 feet above the sediment, the columns were perforated with holes bored by marine animals. It is inferred, therefore, that between the years 235 and 1749, the land on which the temple stood sank until the water was 21 feet above the bottoms of the columns, and then rose again so that the floor of the temple was above sea-level.

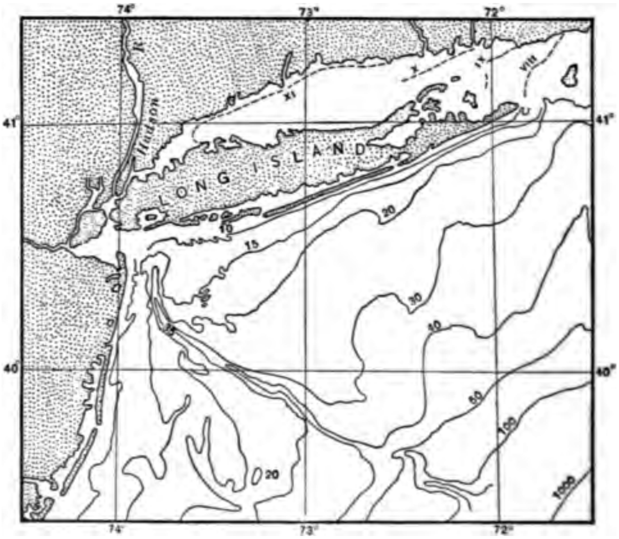

Fig. 313.—The submerged valley which is believed to be the continuation of the Hudson Valley. The position of the valley is indicated by the contours. (Data from C. and G. Survey.)

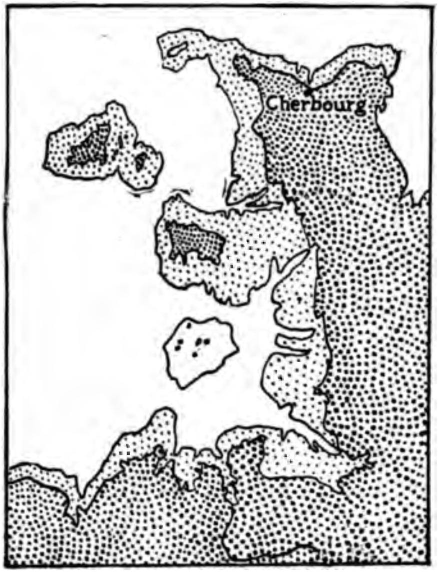

Fig. 314.—The coast of Cotentin, France. The area of light shading has been submerged within historic time. Scale, 30 miles to the inch. (Robin.)

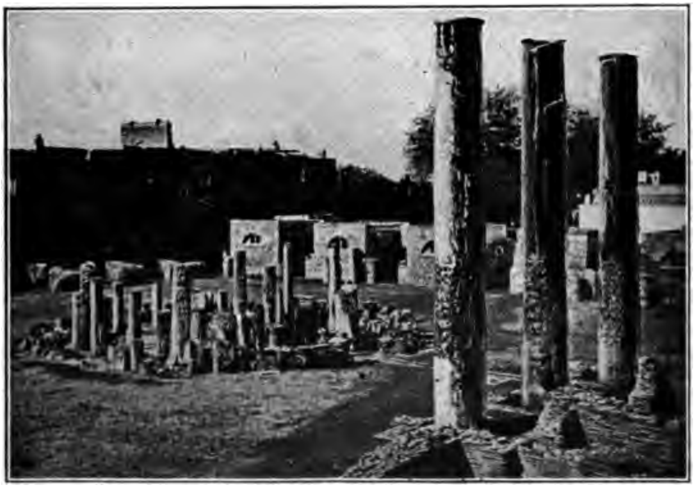

Fig. 315.—The columns of the temple of Serapis, near Naples, Italy.

These illustrations show that the land and sea change their relations to each other. It is probable that this has been true since lands and seas came into existence. It is not always possible to say whether it is the land or the sea-level which has changed; but it seems probable that the sea-level rises and falls from time to time, and that the surface of the land also moves.

Does the Sea or the Land Change Level?

There are several things which may make the sea-level rise or fall. 1. If, for example, the bottom of the sea-basin were to sink, the surface of the sea would be made lower. 2. Again, the gravel, sand, and mud washed down from the land to the sea and deposited in its basin must make the sea-level rise. 3. Lavas poured out from volcanoes beneath the sea would have the same effect. 4. When great ice-caps develop on the land, the water locked up in the ice came from the sea, and the withdrawal of this water from the sea must lower its surface. When the ice melts again, the return of the water to the sea would cause its level to rise. Many other factors also enter into the problem, but they need not be mentioned here.

From the fact that old shore-lines are sometimes warped, it seems clear, on the other hand, that some of the changes along coasts are due to movements of the solid parts of the earth.

On the whole, it seems probable that the sinking of portions of the solid part of the earth is more common than their rise, because the earth is cooling and therefore shrinking; and shrinking means bringing the outside nearer to the center; that is, the lowering of the surface.

Changes of Level in the Interiors of Continents

Changes of level are perhaps as common in the interiors of continents as along coasts, but they are not so easily detected, since there is, away from the coast, no level surface like the sea with which to make comparisons. There are raised beaches about many lakes, as about the Great Lakes, and Great Salt Lake (Fig. 316); but raised beaches about a lake may result from the lowering of the lake, either by the cutting down of its outlet or by great evaporation.

They do not, therefore, prove a rise of the land. In many cases, the old shore-lines about lakes are not level, as they must have been when formed. Some parts of the old shore-line about Lake Bonneville (p. 225) are 300 feet higher than other parts of the same line. An old shore-line about the east end of Lake Ontario is more than 400 feet above the lake, while the same shore-line, traced westward, passes beneath the water at the west end of the lake. Such warped shore-lines are found about many lakes, and show that the surface about the lake basins has suffered movement since the shore-lines were formed.

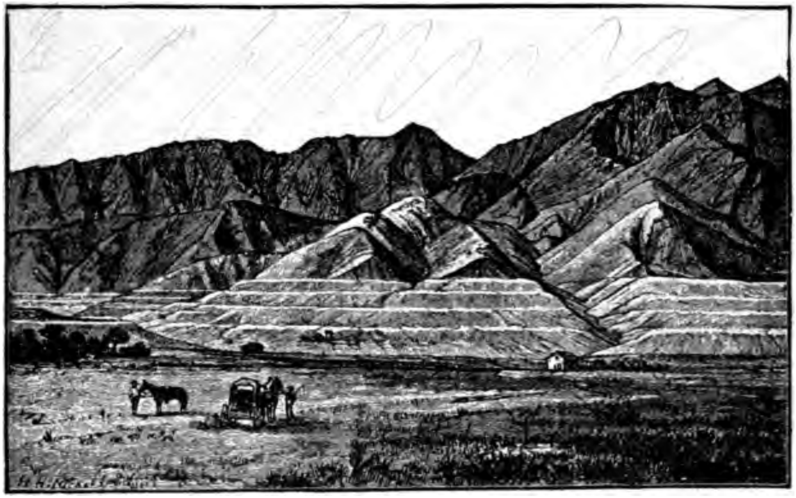
Fig. 316.—Shore of former Lake Bonneville, Wellsville, Utah. (U. S. Geol. Surv.)

These changes of level are still in progress. Thus the area of the Great Lakes is being tilted even now. The movement is downward, relatively, to the southwest. The rate of tilting has been shown to be less than six inches per hundred miles per century.

So widespread are the evidences of changes of level that it may be said, with much probability, that more of the earth's surface has been sinking or rising in recent times, than has been standing still. This general statement seems to point to great instability of the earth's crust; but it should be added that these changes go on, as a rule, very slowly and quietly. The amount of movement is perhaps a small fraction of an inch a year, more commonly than at a faster rate. At times and places, however, the movements have doubtless been more rapid; but even in these cases it is not to be supposed that the movements were always violent.

Ancient changes of level. Beaches and other features of ocean shores are destroyed in time by erosion, if elevated above the water; but there are still evidences of movements which took place so long ago that no traces of shore-lines remain. Thus layers of rock, deposited as sediment (sand, mud, etc.) beneath the sea, are now found over great areas, far above sea-level. Most of the solid rock beneath the Mississippi basin, for example, was laid down as sediment beneath the sea, as shown by the shells, etc., of the sea animals which it contains. In the Appalachian Mountains, rocks formed in the same way are found up to heights of several thousand feet; in the Rocky Mountains up to 10,000 feet and more; in the Andes up to 16,000 feet, and in the Himalayas to still greater heights. It seems certain, therefore, that the changes of level have been great.

Future changes of level. Not only have changes of level between land and sea been taking place for untold ages, but they are likely to continue. The wear of the land and the transfer of sediment to the sea raises the level of the water by partly filling the basins which hold it. The rise of the water increases the area of the sea and decreases the area of the land. In the past, there seem to have been occasional sinkings of the ocean basins; and when an ocean basin sinks, its capacity is increased and the sea-level is drawn down, just as the surface of the water in a pan would be drawn down if the bottom were lowered. This lowering of the surface of the sea makes the continents *appear to rise*. Such changes are likely to occur in the future, so far as can now be seen, just as they have in the past. It is probable that, in the course of the earth's history, the lowering of the sea-level because of the sinking of the ocean basins has been greater than the rise of the sea-level because of sedimentation from the land. This is perhaps the reason why wind and water and ice have not been able to destroy the continents, though this is their constant aim.

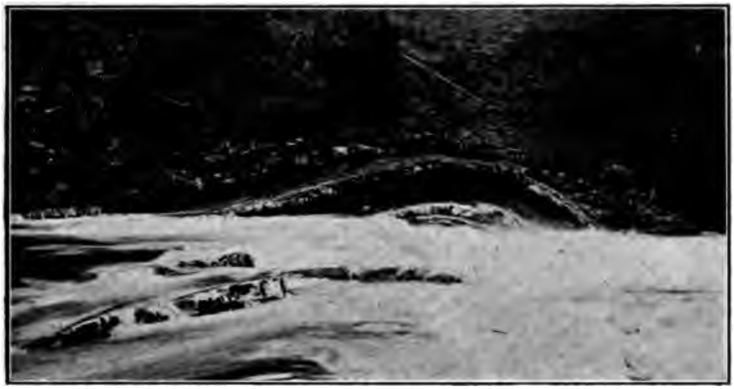

Fig. 317.—A gentle fold in limestone. Dumfriesshire, Scotland. (H. M. Geol. Surv.)

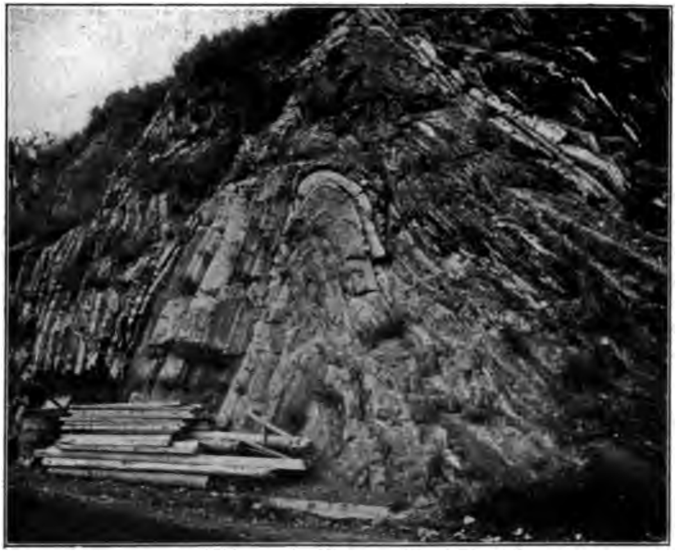

Fig. 318.—Closed anticlinal fold, near Levis Station, Quebec. (U. S. Geol. Surv.)

Types of Crustal Deformation

Changes of level imply *deformation* (bending, breaking, etc.) of the outside of the solid part of the earth. This deformation takes the form of (1) gentle *warping*, (2) *folding*, and (3) *faulting*.

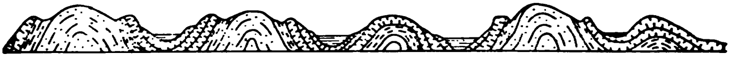

Fig. 319.—Section of the western part of the Jura Mountains.

Warping and folding. Sedimentary rocks were originally laid down in nearly horizontal beds, just as sediments are being laid down at the present time. But the rock strata of most parts of the land are slightly deformed, and in many places their positions have been greatly changed. The warping may be slight, resulting in slight arching (Fig. 317), or it may be so great that the arches become close folds (Fig. 318).

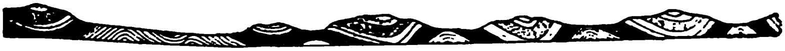

Fig. 320.—Diagram showing the position of the beds of rock in the Appalachian Mountains. (Rogers.)

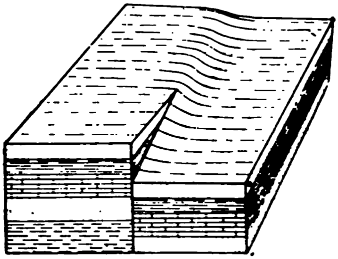

Fig. 321.

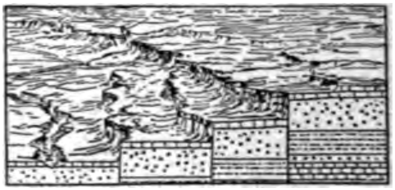

Fig. 322.

Fig. 321.—Fault passing into a monoclinal fold.
Fig. 322.—A branching fault. (Powell, U. S. Geol. Surv.)

Warping and folding give rise to great topographic features; but in most mountains of folded rock, the present topography is the result of erosion rather than of the original folding. The structure of the rock resulting from the folding has, in many cases, determined or greatly influenced the topography which has resulted from erosion (Fig. 320).

Faulting. At many times and in many places portions of the earth's surface have sunk or risen along a deep crack, or *plane of fracture,* as shown by Figs. 321 and 322. The slipping along such a plane of fracture is a *fault.* One type of fault is shown in Fig. 323, where the overhanging side (at the left) has sunk. Such a fault is called a *normal fault,* because it is the commoner type. In the other type (Fig. 324), the opposite side has sunk relatively. This sort of fault is called a *thrust fault,* because it shows that it was made under pressure (thrust) from the sides.

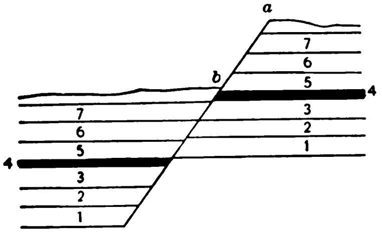

Fig. 323.

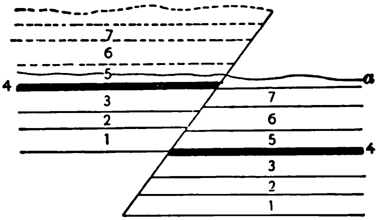

Fig. 324.

Fig. 323.—A normal fault. The overhanging side (to the left) has sunk; *a b* = fault-scarp.

Fig. 324.—A thrust fault. The dotted lines at the left show the portion which has been removed by erosion. The present surface is shown by the line to the left of *a*.

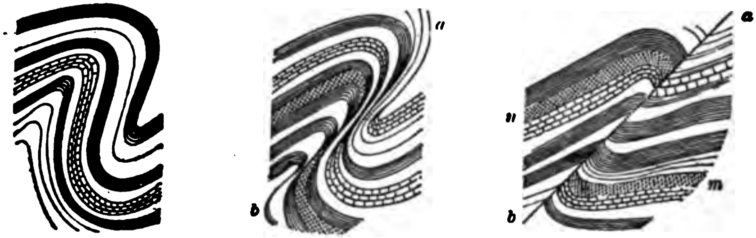

Fig. 325.—Diagram showing relations of faults and folds.

Faults of both types are common; but thrust (or *reversed*) faults are common only in regions where the rocks have been folded. Fig.

325 suggests a common relation between a thrust fault and a fold. A fold which is not faulted sometimes passes into a thrust fault, as shown by Fig. 325.

Cliffs due to faulting are called *fault-scarps* (*a b*, Fig. 323). Fault-scarps, like other steep slopes, are in time destroyed by erosion. Some faults, however, were so recent that their scarps are still distinct, as in the plateau and basin regions west of the Rocky Mountains.

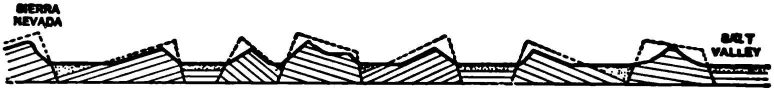

Fig. 326.—A type of mountain structure seen in the ranges of the Great Basin. Length of the section, 120 miles. (Gilbert.)

Many of the more striking topographic features of that region, including numerous mountain ranges, are the result of such movements. The bold fronts of some of these mountains are fault-scarps (Fig. 326).

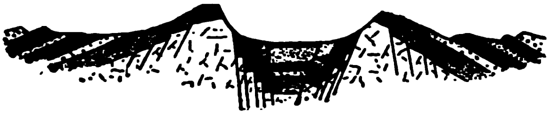

Fig. 327.—Section across the Vosges and Black Forest mountains. (Penck. From Geikie's Earth Sculpture, by permission of G. P. Putnam's Sons.)

There is sometimes horizontal as well as vertical movement along a fault plane. This was the case in the fault which caused the earthquake of California, in the spring of 1906.

Earthquakes

Definition. Earthquakes are tremblings or quakings of the earth's surface, due to causes with which man has nothing to do. The passing of a railway-train causes the surface of the ground to vibrate, and this vibration is often felt in buildings near the track. In this case the cause is readily understood, and the shaking is not called an earthquake; but an equal amount of quaking, due to happenings beneath the surface not caused by man, would be called an earthquake, especially if felt over a wide area.

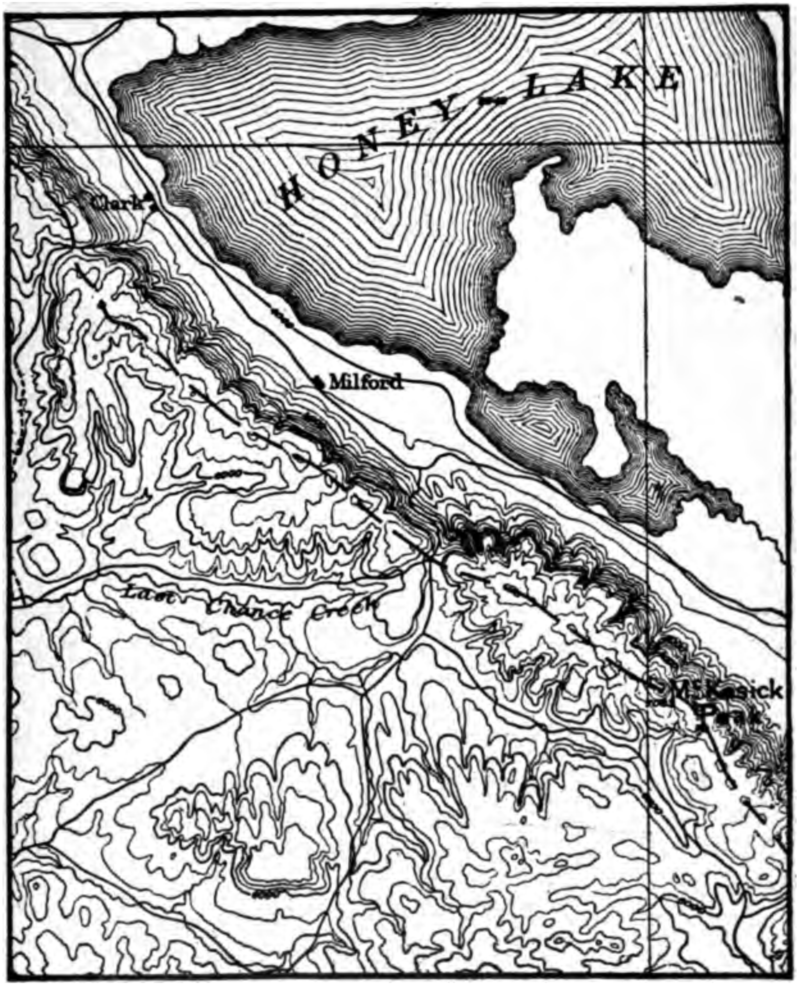

Fig. 328.—A topographic map showing a steep mountain slope between Clark and McKesick Peak, which is a fault-scarp. Scale about 4 miles to the inch. (Honey Lake, Cal. Sheet, U. S. Geol. Surv.)

Strength and destructiveness. Earthquakes vary much in strength. Some are so gentle that they are barely felt, while others are so violent that buildings are overthrown, crevasses opened in the surface of the land, and masses of rock loosened from cliffs.

Besides quakings which are felt, there are many earth tremors so slight that they are known only by means of delicate instruments set up for the purpose of recording all vibrations of the surface, no matter how slight. The number of tremors too slight to be noticed is far greater than the number of earthquakes strong enough to be felt.

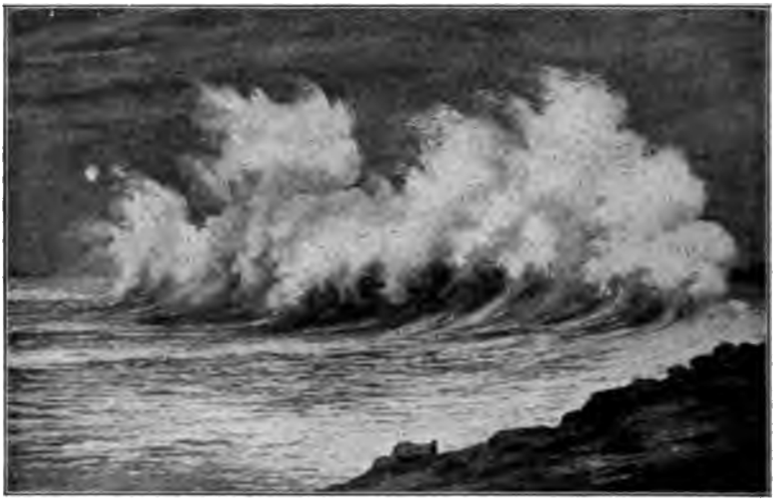

Fig. 329.—Great sea-wave on the coast of Ceylon. (Sieberg.)

Although violent earthquakes are sometimes very destructive to buildings and to life, the actual movement of the land surface is usually very little. It is commonly measured in millimeters (a millimeter is about $\frac{1}{25}$ of an inch) rather than in inches or feet. Bodies on the surface often move much more than the ground does. The relation between the two is illustrated by the fact that a blow on the floor may cause a ball which rests upon it to bound up inches or even feet, though the floor itself moves but a small fraction of an inch.

While violent earthquakes are among the most terrible of natural phenomena, so far as human affairs are concerned, those of historic times, at least, have left few important marks on the surface of the earth. Their destructiveness to human life comes largely from the fall of buildings, and from the "great sea waves" (Fig. 329) caused by the earthquakes. The great destruction of life by earthquakes often results from the advance of these waves upon a low coast which is densely populated. In the Lisbon earthquake of 1755 a wave 60 feet high swept up on the shore and destroyed some 60,000 human lives. Vessels in harbors have been swept in by waves and left high and dry above the water-level.

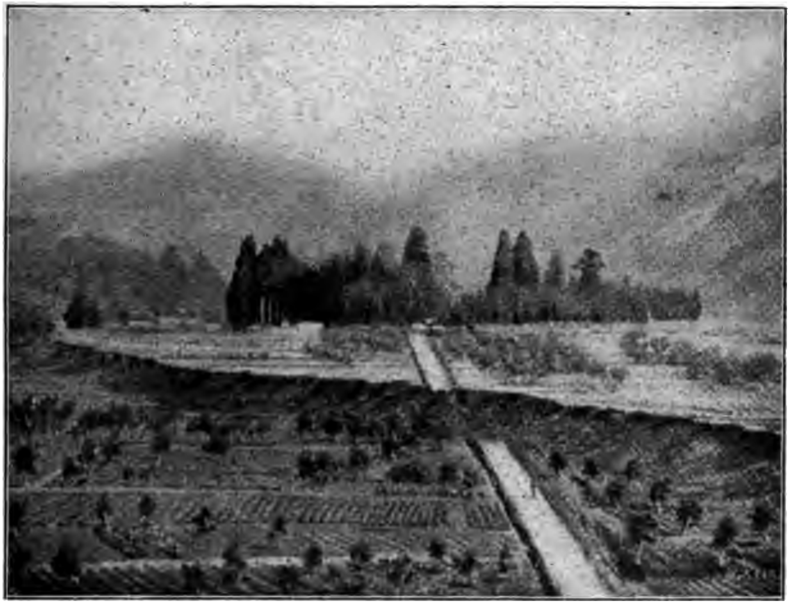

Fig. 330.—Fault in Japan, 1891. (Koto.)

Examples. Some of the principal features of earthquakes may be brought out by the study of a few striking examples.

On October 28, 1891, an earthquake on Nippon, the main island of Japan, opened a fissure traceable for over 40 miles. The ground on one side of this fissure sank 2 to 20 feet (*a fault*) below that on the other. At the same time the east wall of the fissure was pushed about 13 feet northward (Fig. 330). During this earthquake over 7,000 people were killed, 17,000 injured, and some 20,000 buildings were destroyed.

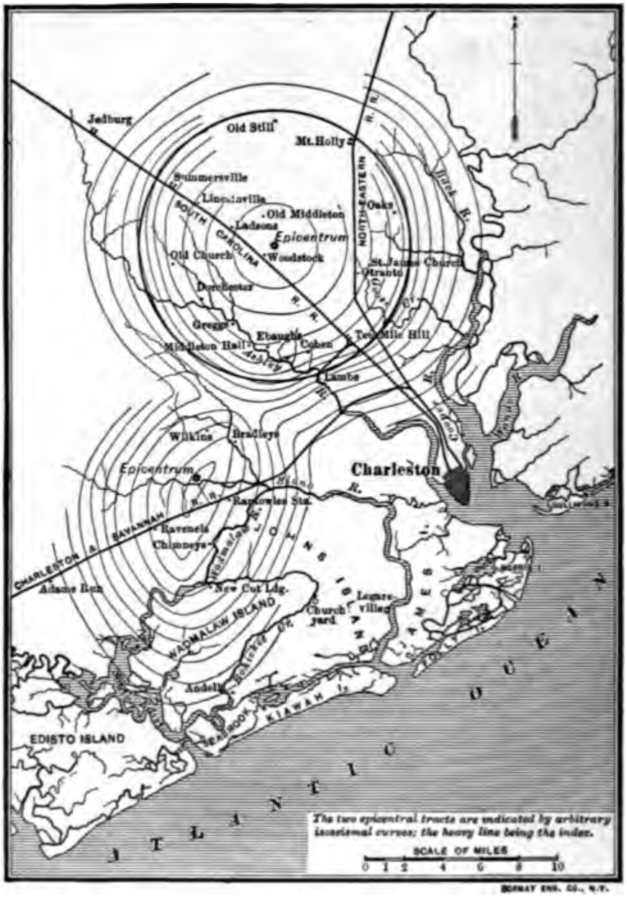

Fig. 331. Chart showing the two centers from which the earth waves in the Charleston earthquake spread. The curved lines connect points where the quaking was equally strong. (U. S. Geol. Surv.)

On the evening of August 31, 1886, the city of Charleston, South Carolina, was disturbed by an earthquake which was felt over much of the eastern part of the United States. Strange noises and slight tremblings of the earth had been noted for several days previous to the destructive quaking, but they excited no great alarm. About ten o'clock in the evening of the fateful day, a low rumbling sound was heard, which rapidly deepened into an awful roar. The slight trembling of the ground increased until it became destructively violent. The motion then subsided slightly, but increased again, and then died away. The violent disturbance lasted 70 seconds. A second shock, almost as severe as the first, occurred eight minutes later. Six or seven other less severe shocks were felt before morning, and slight tremors were felt at intervals until the following April. During the shocks, buildings swayed, chimneys were thrown down, walls were cracked, houses moved from their foundations, railroad-tracks displaced and the rails bent, and trees disturbed in the ground. Numerous fissures were formed in the earth, and from some of them streams of water, mud, and sand were forced out. Hardly a large building in the city but was damaged, and 27 persons were killed, chiefly by falling masonry. The people fled in terror from their homes, and for several days and nights a large part of the population camped in the public parks.

Outside the vicinity of Charleston the earthquake shock was less violent, but the quaking was felt over an area of between 2,000,000 and 3,000,000 square miles. It was felt earliest near Charleston, and later at increasing distances from the city. There were two centers of disturbance (Fig. 331), and the earthquake spread like a wave from them at the rate of about 150 miles per minute.

In 1822 and again in 1835 the coast of Chile was shaken by earthquakes for 1,200 miles. In both years the shocks continued for several months. When they were over, it was found that the coast lands had been elevated 2 to 4 feet.[1] In 1835 a volcano broke out beneath the sea (San Fernandez Island) at the time of the earthquake shocks on the coast, and many of the Andean volcanoes were active.

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[1] This statement has been disputed, and the records which bear on the point seem to be imperfect.

In 1819 a part of the delta of the Indus River experienced a series of shocks lasting four days. During the earthquake an area some 2,000 square miles in extent sunk so as to be covered by the sea, while a neighboring belt, 50 miles long and 16 miles wide,

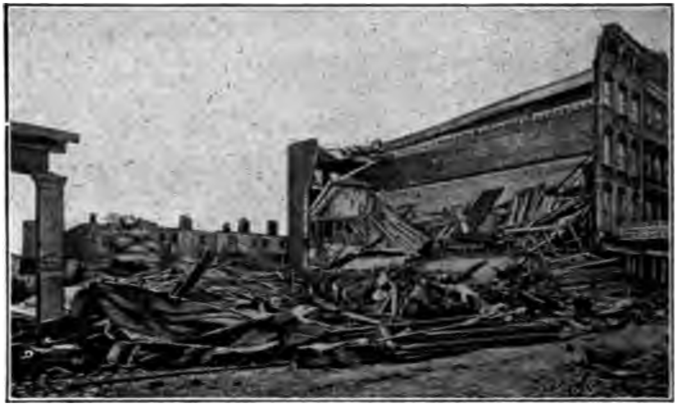

Fig 332.—A wreck caused by the Charleston earthquake. (U. S. Geol. Surv.)

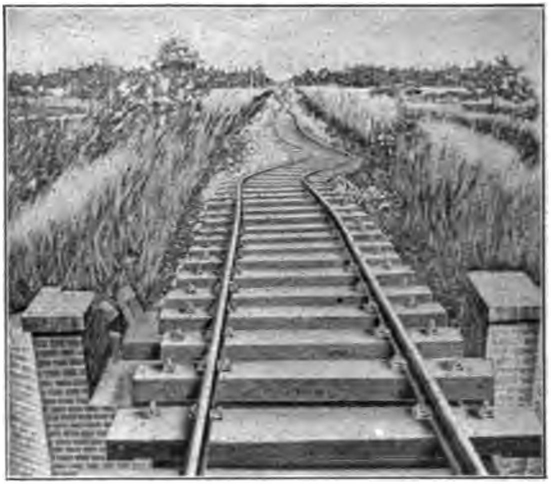

Fig. 333. —The bending of railway track in India: earthquake of 1897. (Oldham.)

rose about 10 feet. The earthquake of Kangra, in the same country, April, 1905, affected an area of 1,625,000 square miles, and killed about 20,000 people. In this case the vibrations spread from two centers, and traveled at the rate of about two miles per second. The same region had been shaken in 1897.

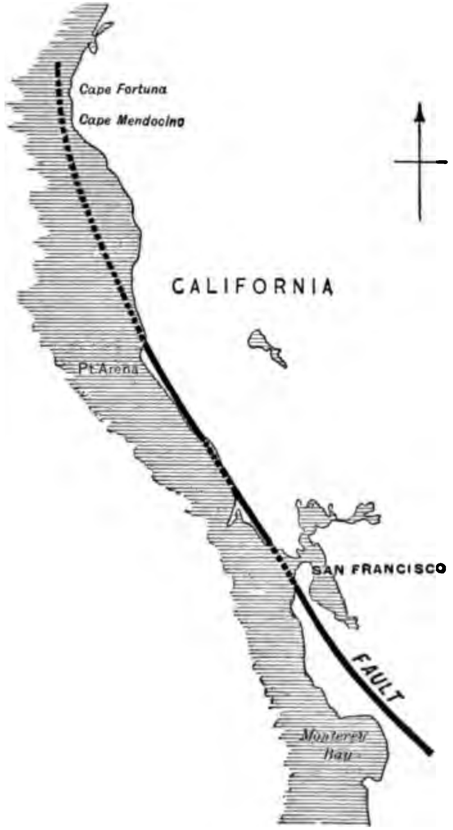

Fig. 334.—Sketch-map of the coast of California, showing the course of the great fault along which movement took place during the earthquake of 1906.

A series of earthquake shocks, lasting from 1811 to 1813, affected the Mississippi Valley just below the mouth of the Ohio. Many fissures were formed in the deposits of the flood plain of the Mississippi, and some of them remained open for years. Parts of the flood plain sank, and the sunken portions gave rise to marshes and lakes, some of which still remain, with the trunks of the drowned trees still rising above the water. The Orleans, the first steamboat built west of the Appalachians, narrowly escaped destruction at New Madrid.

At about the same time, 1812, nearly 10,000 persons were killed in a violent earthquake which destroyed Caracas, Venezuela.

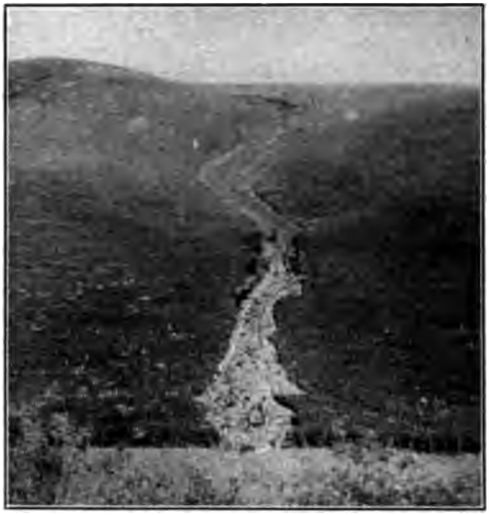

Fig. 335.—An "earth flow," or landslide, which occurred during the California earthquake, several miles west of the fault line, east of Half Moon Bay. (Dudley.)

Earthquakes have been most destructive in southern Italy. Some 20,000 lives were lost in 1688, 43,000 more in 1693, and 32,000 more in 1783,— in all about 100,000 in a single century.

On April 18, 1906, there was a destructive earthquake on the coast of California, in and about San Francisco. Many buildings were injured by the earthquake, and some practically destroyed, and a large part of the city was burned by the fire which followed. The quaking had injured the water-works of the city, so that water was not available for fighting the flames. This earthquake, the most disastrous in North America in historic times, was caused by a horizontal fault of eight to twenty or more feet. The line of the

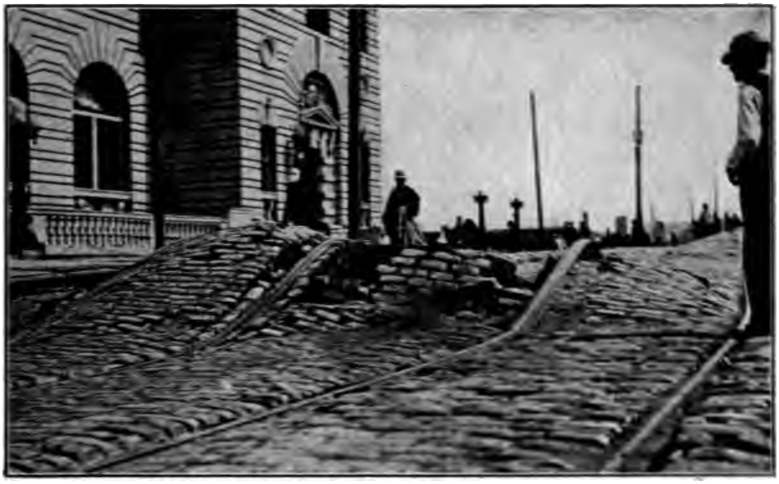

Fig. 336.—Deformed railway, Seventh and Mission Streets, San Francisco. (U. S. Geol. Surv.)

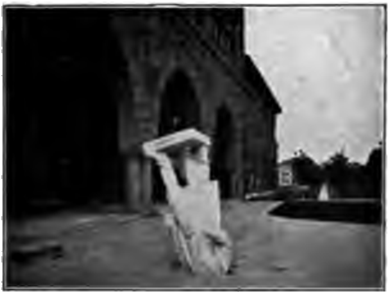

Fig. 337.

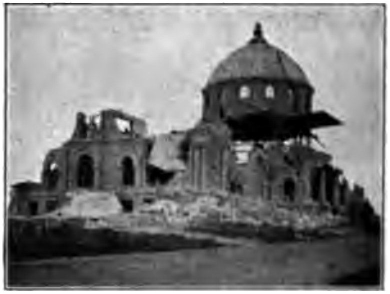

Fig. 338.

Fig. 337.—The Agassiz statue, Leland Stanford University, after the earthquake of April, 1906. (Branner.)

Fig. 338.—The Library, Leland Stanford University, after the earthquake of April, 1906. (Branner.)

fault was traced some 300 miles on land (Fig. 334). Figs. 335–338 show some of the results of this earthquake.

Earthquakes starting beneath the sea. Earthquakes sometimes seem to start beneath the sea, and to spread thence to the land. The record of the changes which take place beneath the sea during an earthquake is rarely distinct, but in a few cases some facts are known about them. This is especially the case with reference to some of the earthquakes about the coast of Greece, for in a number of cases cables have been broken, and soundings taken when they were mended gave some idea of what had happened. In one case, the soundings from the bow and the stern of the vessel which repaired the cable showed differences of more than 1,500 feet in the depth of the water, *where the bottom had been nearly level when the cable was laid.*

Frequency. Earthquakes are very common, though fortunately those which are violent enough to be destructive are rare. From 1889 to 1899, an average of 36 per year were recorded in California alone, but most of them were so slight as to do no damage. In Japan, earthquakes have been recorded at the rate of several a day for many years, but many of them are very slight, and only a few violent enough to be destructive.

The Isthmus of Panama and its surroundings were under careful observation with reference to earthquakes for a few years, because the frequency and violence of earthquakes have a bearing on the site which should be chosen for the canal which is to join the Atlantic and Pacific. In 40 months, between January, 1901, and April, 1904, 169 earthquakes were recorded at San José, near the eastern end of the proposed Nicaraguan route. Of these, 43 were mere tremors, 91 slight shocks, and 35 strong shocks. During the same period, 6 tremors and 4 slight shocks were recorded at Panama, near the site of the route along which the canal is being dug.

In view of what is now known of earthquakes and other slight tremors, it has been said that *some part of the earth's surface is probably shaking all the time,* though shocks sufficiently violent to be destructive to life are few.

Distribution. Earthquakes are perhaps most common in volcanic regions, though not confined to them. It can hardly be said that such earthquakes are caused by volcanoes, since many of them do not occur at the time of volcanic eruptions.

Many great earthquakes have been near the edge of the continental platforms. Mountain regions in general seem to be more subject to earthquakes than plains, though earthquakes originating in mountain regions sometimes spread to plains. Earthquakes, on the other hand, are not confined to mountain regions. As in the case of the Charleston earthquake, they sometimes originate beneath plains.

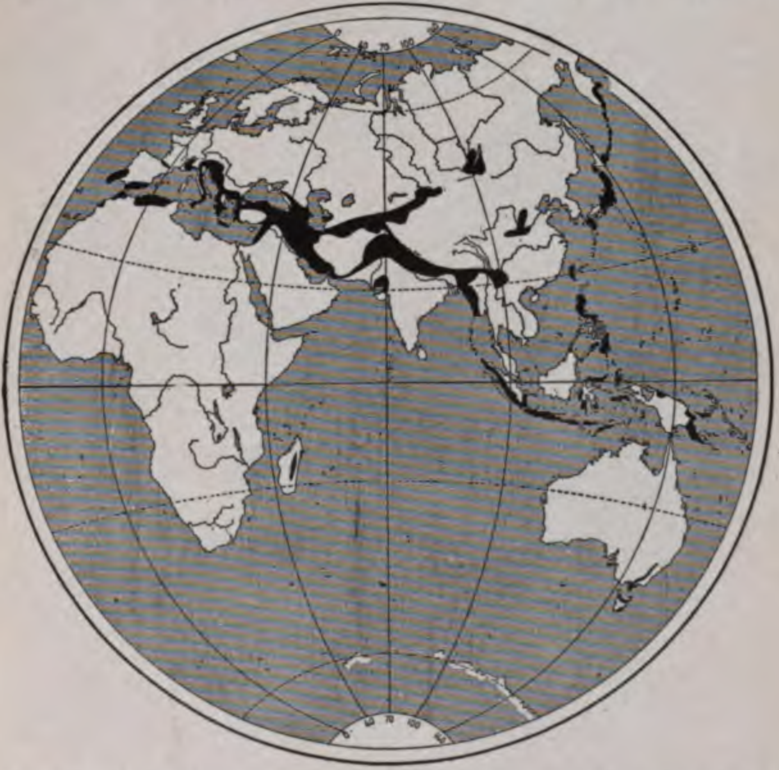

Fig. 339.—Map showing in black the principal earthquake regions of the Old World. (Montessus de Ballore.)

Causes of earthquakes. Earthquakes are probably due to various causes. Small ones are perhaps sometimes due to the falling in of the roofs of underground caves. If the roof of Mammoth Cave, for example, were to fall in, there would be a slight earthquake in the vicinity. Earthquakes accompany violent volcanic eruptions, and in these cases the explosions which cause the eruption are doubtless the cause of the earthquakes. Great landslides and avalanches may cause slight earthquakes, and it is probable that slumping on the slopes of deltas and on the outer faces of the continental shelves produces similar results.

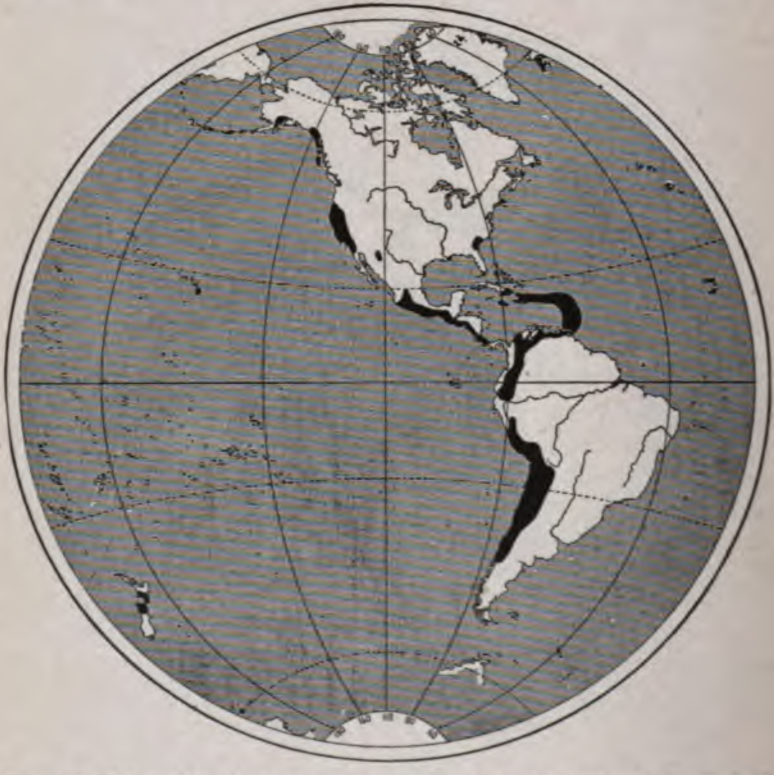

Fig. 340.—Map showing the principal earthquake regions of the New World. (Montessus de Ballore.)

Many great earthquakes are connected with other forms of crustal movement. As already noted, fissures are sometimes opened in the surface of the land during an earthquake. This is best seen where there is little or no soil, and where the solid rock lies close to the surface. There is a great crack of this sort in Arizona (Fig. 341), and similar fissures have been formed in New Zealand, Japan, and elsewhere during earthquakes. It is not always clear whether the fissure should be looked on as the cause or the result of the earthquake. In some cases (p. 289) it is found that one side of such a fissure is higher than the other, indicating that the rock on one side was raised or that of the other sunk, or both; in other words, that the strata have been *faulted*. *Faulting* is probably the cause of the great earthquakes. The slipping of one great body of rock past another would cause vibrations which would spread far from the center of disturbance.

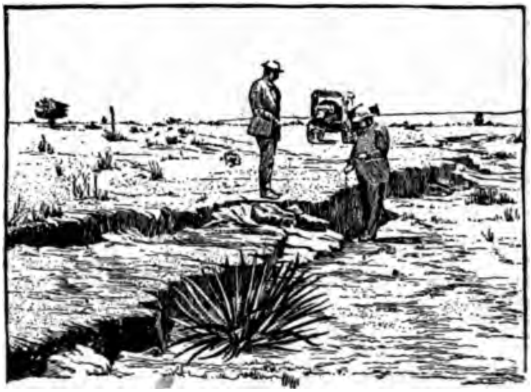

Fig. 341.—Fissure produced by earthquake. Arizona.

Again, great thicknesses of rock strata are sometimes found folded and crumpled. The process of mountain folding has never been seen, and it is probably much too slow to be seen from day to day, or from year to year. But there can be no doubt that beds now folded so as to stand on edge were once horizontal or nearly so. No series of horizontal beds can be folded, as many beds have been, without more or less slipping of layer on layer. The amount of slipping at any one time may be slight, but it must be real. This, too, is probably a cause of earthquakes, and of earth-tremors which are not felt.

It is probable that most earthquakes are to be looked upon as but one expression of the widespread movements to which the crust of the earth is subject, movements which are due primarily to the continued adjustment of the outside of the earth to a shrinking interior. In general, these movements are too slow to produce vibrations which we can feel; but they are sufficient sometimes to produce great earthquakes.

Surface changes caused by earthquakes. The changes in the surface of the land made by earthquakes are numerous if not important. Besides the cracks and fissures, and the risings and sinkings of surface, which have been noted, drainage is often disturbed. This is partly because of the cracks and fissures which are opened, and partly for other reasons. If a fissure is opened across the course of a stream, the stream will plunge into it. Springs are often disturbed, old ones ceasing to flow and new ones appearing. This is probably because the earthquake movement has broken the rock beneath the surface, and so changed the course of the groundwater circulation. Temporary spouting springs are sometimes formed, water being forced up violently through them. This was the case in the Charleston earthquake. Earthquakes sometimes cause landslides, and if the material from a mountain-side slides down, it may dam the valley below so as to disturb its drainage.

From fissures and from lesser vents noxious gases sometimes issue.

Earthquake waves have a singularly destructive effect upon animals which live in the water. In many cases animals of rivers, bays, and even of the ocean have been killed in extraordinary numbers during an earthquake.

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2. SHALER, Chapter in *Aspects of the Earth:* Scribners.
3. GILBERT, Pop. Sci. Mo., Vol. LXIX, 1906, p. 97.
4. JORDAN, Pop. Sci. Mo., Vol. LXIX, 1906, p. 289.
5. RANSOME, Nat. Geog. Mag., Vol. XVII, 1906, pp. 280 and 325.

CHAPTER IX

TERRESTRIAL MAGNETISM

The earth is a great magnet, and, like the small magnets with which we are familiar, has two poles. One of these poles is called the *North Magnetic Pole,* and the other the *South Magnetic Pole.* One end of the compass needle points toward one of these poles, and the other toward the other. If we were to follow the directions pointed by the compass needle, we would be led to the North Magnetic Pole in the one case, and to the South Magnetic Pole in the other. The *magnetic meridians* (Fig. 342) connect the magnetic poles. No one has ever reached the North Magnetic Pole unless it be Captain Amundsen in his expedition which ended in 1906. He reports that the North Magnetic Pole is not a point which can be definitely located at the surface. Its position, calculated from the directions in which the compass needle dips at various stations in the vicinity, is in latitude somewhat above 70° N. and in longitude between 97° and 98° W. The South Magnetic Pole was reached by members of the Shackleton expedition (Professor David in charge) in January, 1909, and is in latitude 72° 25′ S., longitude 155° 16′ E., where the surface has an elevation of more than 7000 feet.

The magnetic poles are therefore far from the geographic poles, and they are not exactly opposite each other. Their positions appear to shift a little from year to year, but the change is not known to be great. The North Magnetic Pole is thought to have shifted its position some 50 or 60 miles in as many years, following 1830.

Since one end of the magnetic needle points to the North Magnetic Pole, it follows that the compass does not indicate true north and south in many places. At points north of the North

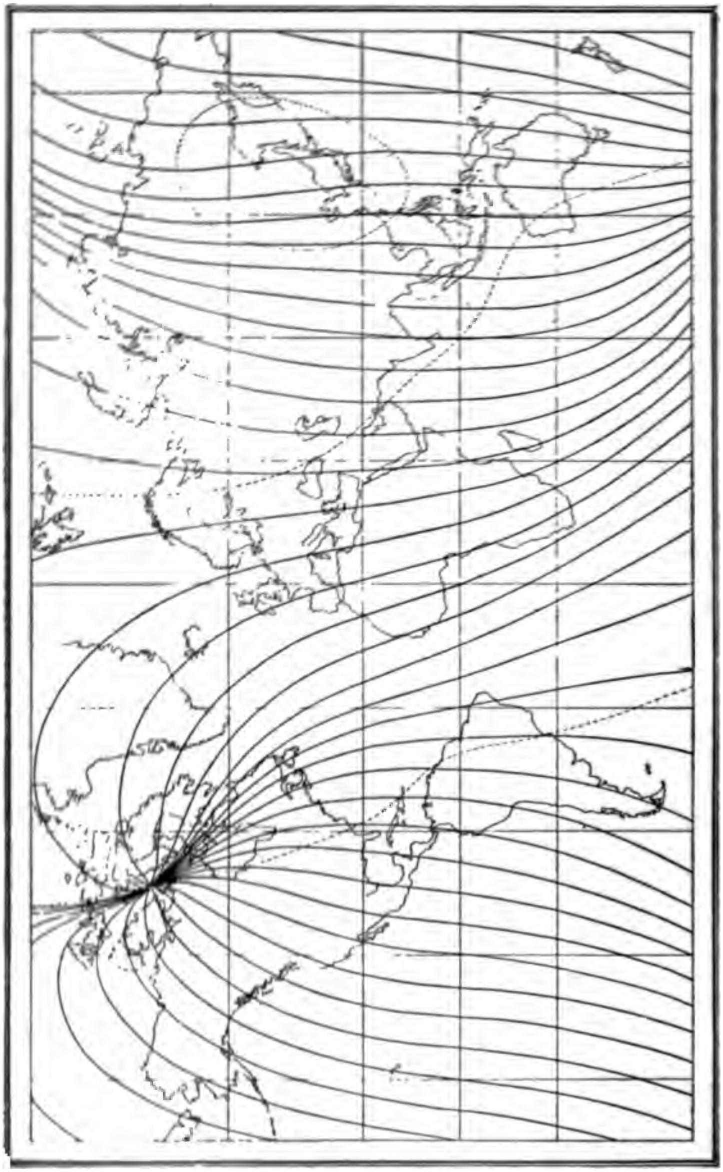

Fig. 342.—Magnetic meridians for 1885.

Magnetic Pole, the "north" end of the needle points in a southerly direction. At points to the east of the same pole, it points westward, and at points west, eastward. The departure of the needle from the true north and south is *magnetic declination.* A line connecting places of no declination is an *agonic line,* and lines connecting places of equal declination are *isogonic lines.*

Fig. 343 shows an agonic line in the United States running from Lake Superior to South Carolina. On this line the magnetic

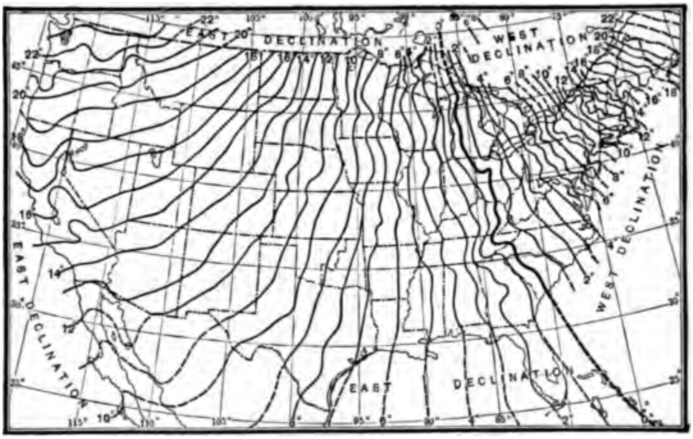

Fig. 343.—Lines of equal magnetic declination for the United States, 1902. The heavy line is an *agonic line,* or line of no declination. (U. S. C. and G. Surv.)

needle points due north and south. At all places east of this line the needle points west of true north, and such places have *west declination.* All places west of this agonic line have *east declination.* In general, declination increases with increasing distance from the agonic line. At New York City the declination is about 10° W., and in Maine it is more than 20° W. at a maximum. At Chicago the declination is about 3° E., at Denver about 13° E., at San Francisco about 16° E., and in the State of Washington more than 20° E. (Fig. 343).

It will be seen that it is necessary to know the magnetic declination of a region, if the compass is to be used there for determining

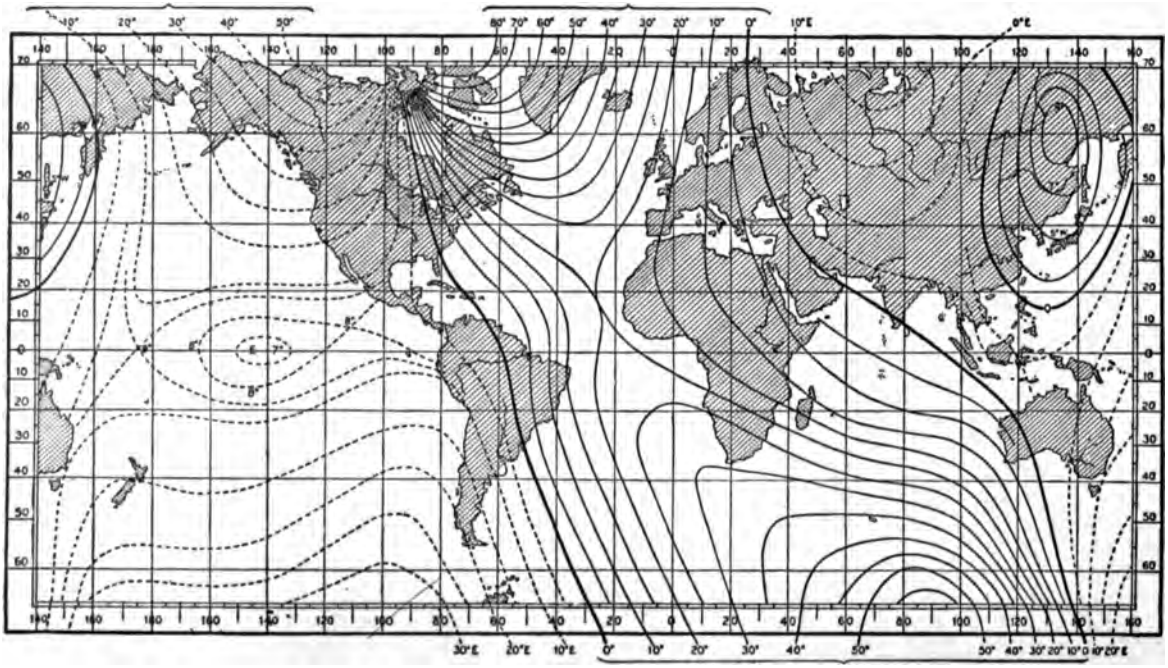

Fig. 344.—Lines of equal magnetic declination, 1905. (British Admiralty.)

directions accurately. The declination being known, the compass is of great value to travelers through forests and other tracts which have no roads or trails. By its help directions may be known accurately. The compass, too, is of the greatest help on the sea, where vessels are guided by it.

The declination at a given place does not remain quite constant. The declination at Chicago, for example, has shifted more than 2° since 1820.

PART II

EARTH RELATIONS

CHAPTER X

FORM, MOTIONS, LATITUDE, AND LONGITUDE

Form. The form of the earth is very much like that of a sphere, but since it is not exactly a sphere, it is called a *spheroid*. The form has been determined in various ways: (1) Ships have sailed quite around it. This proves that it is everywhere bounded by curved surfaces, but it does not prove that it is a sphere or even a spheroid, for it would still be possible to sail around it if it had the shape of an egg. (2) When a vessel goes to sea, its lower part disappears first, and when a vessel approaches land, its highest part is seen first from the land. By people on the vessel, the highest lands are seen first, and the low ones later; and the spires and chimneys of houses appear before the roofs, and the roofs before the lower parts. Like (1) above, these facts show only that the earth has a curved surface. But from whatever port vessels start, and in whatever direction they sail, objects on land disappear at about the same rate. This means that *the curvature is nearly the same in all directions.* A body whose curvature is the same in all directions is a sphere, and a body whose curvature is nearly the same in all directions is nearly a sphere. This is the condition of the earth. (3) Again, the earth sometimes gets directly between the sun and the moon. It then casts a shadow on the moon, making an eclipse of the moon, and this shadow always appears to be circular. In these and other ways it is known that the form of the earth does not depart greatly from that of a sphere.

Size. The circumference of the earth is nearly 25,000 miles, and its diameter nearly 8,000 miles. Since the earth is not a

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perfect sphere, its various diameters and circumferences are not exactly equal. Its longest diameter is 7,926.5 miles, and its shortest nearly 27 miles less (7,899.7 miles). The shortest circumference is about 42 miles shorter than the longest.

The area of the earth's surface is nearly 197,000,000 square miles, and its volume, exclusive of the atmosphere, about 260,000,000,000 cubic miles. The earth is between five and six times as heavy as an equal volume of water would be.

Motions

The earth has two principal motions: (1) it rotates on its shortest diameter, which is called its *axis*, and (2) it revolves around the sun. The axis is an imaginary line, and its ends are the *poles*. The circumference midway between the poles is the *equator*.

Rotation. The rotation of the earth is shown by a simple experiment. If a body is dropped from a high tower, it does not fall to a point immediately beneath that from which it started. Instead, it always falls a little to the east of the point from which it started. This is explained by the rotation of the earth. If the earth rotates, any point must move faster than any other point which is nearer its axis, for the same reason that a point on the rim of a wheel moves faster than a point between the rim and the hub. If the earth is rotating, the top of a tower must be moving forward faster than its bottom, and the body which falls from the top must start with a *forward* velocity greater than the forward velocity of the base of the tower. Under these circumstances, the falling body must move forward *relative to the base of the tower.* If the earth rotates to the east, the body will fall to the east.

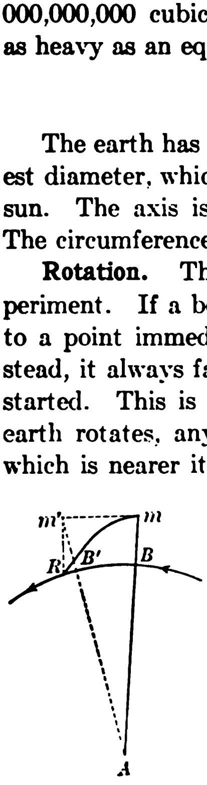

Fig. 345.—Figure to illustrate the effect of rotation on a falling body, as explained in text.

Fig. 345 illustrates the principle involved. Let AB = the earth's radius, and m a point on a tower (height greatly exaggerated) above the earth's surface. Suppose the mass m is dropped *from the top.* If the earth were not rotating, it would fall straight down, and would strike the surface at *B*. Suppose, however, the earth is rotating at such a rate that *B A* turns to *B′A* while m is falling to the surface. If it were not for the attraction of the earth, m would go in a straight line to *m′* The attraction of the earth is at right angles to this line (*m m′*). It does not change the amount of motion of m toward *m′*, but it gives it another motion toward the earth. The result is that it describes the curved line *m R*, and strikes the earth at *R*, a little beyond the foot of the perpendicular *m′B′*.[1] If the earth rotated to the west, the body would fall the other way. Since the body always falls to the east, and since nothing but the rotation of the earth to the east will explain this fact, it is taken as a proof that the earth rotates in that direction.

Other experiments also prove the rotation of the earth, but they are not so simple as the one mentioned above, and will not be described here.

The form of the earth is consistent with its rotation, but can hardly be said to prove it. Any rotating body which is not perfectly rigid would be flattened at its poles, and bulged at its equator. The amount of flattening would depend on (1) the rate of rotation and (2) the rigidity of the body. The faster the rotation and the less rigid the body, the greater the flattening.

The rate at which a point on the surface of the earth moves, as a result of rotation, varies greatly. Points on the equator move fastest, because they have farthest to go in the time of one complete rotation. At the equator, where the circumference is nearly 25,000 miles, a point moves nearly 25,000 miles a day, as a result of rotation. Half-way between the equator and either pole, the rate is about 17,600 miles per day, while at the poles the rate is zero.

Effect of rotation. Rotation gives us day and night, for one side of the earth and then the other is turned toward the sun during each rotation. The time of rotation, 24 hours, determines the length of a day (day and night).

Revolution. No simple experiment proves that the earth revolves about the sun, but the fact of revolution is known in various ways. The length of time which it takes the earth to make its circuit about the sun fixes the length of the year, and is a little more than 365 days.

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[1] Moulton's Introduction to Astronomy, pp. 148, 149.

The path of the earth around the sun is its *orbit.* The orbit of the earth is not a circle, but a curve called an *ellipse* (Fig. 346), and

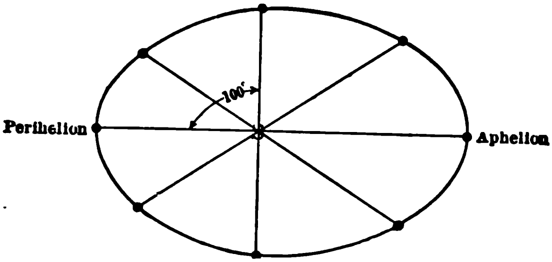

Fig. 346.—The orbit of the earth is an ellipse, with the sun in one of the foci.

the distance of the earth from the sun varies from time to time. When the earth is nearest the sun, the distance between them is about 3,000,000 miles less than when they are farthest apart. The earth is nearest (about 91,500,000 miles) the sun in the early part of the winter of the northern hemisphere (about January 1st), and farthest (about 94,500,000 miles) from it early in the summer.

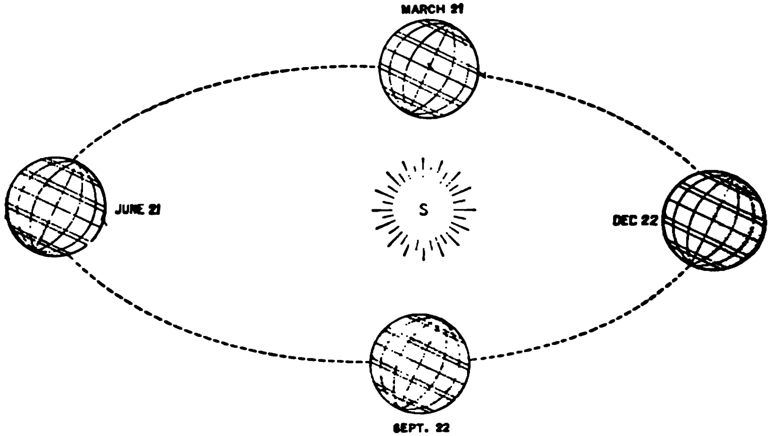

Fig. 347.—Diagram showing the position of the earth with reference to the sun at the solstices and equinoxes.

The motion of the earth through space during its revolution about the sun is at the rate of about 600,000,000 miles a year. This means that the earth travels about 1,600,000 miles daily, 66,666 miles hourly, or more than 1,100 miles each minute.

The earth's axis is inclined toward the plane of its orbit about 23½ degrees (Fig. 347). This position of the axis, together with the motions of the earth, has much to do with the distribution of the heat and light received from the sun, and so with the changes in the length of day (daylight) and night (darkness), and with the seasons. But before attempting to see how these changes are brought about, we must become familiar with certain terms which are to be used in the discussion of these changes.

Latitude, Longitude, and Time

Latitude. The equator has been defined as the circle about the earth midway between the poles. Circles parallel to the equator are *parallels*. The number of parallels which might be drawn is very large, though only a few are represented on maps. The length of parallels varies greatly, those near the equator being longer, and those near the poles shorter. The lines that pass from pole to pole on the earth's surface are *meridians*. All meridians come together at each pole.

A few meridians and parallels are shown in Fig. 348, which shows the earth in two positions. The left-hand part of the figure shows the half of each parallel represented, and the whole of each meridian. The right-hand part shows the relation of parallels to the North Pole. The distance between the equator and

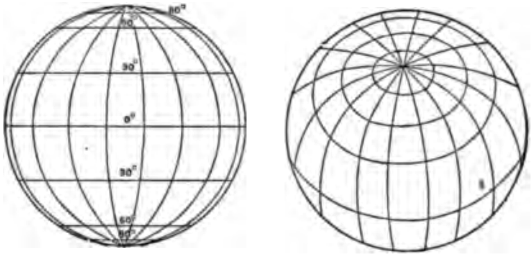

Fig. 348.—Parallels and meridians.

either pole is divided into 90 parts, called ***degrees*** (written 90°). Each degree is divided into 60 parts, called ***minutes*** (written 60′). Each minute is divided into 60 parts, called ***seconds*** (written 60″). Distance north or south of the equator may therefore be determined from a globe or map by means of parallels.

Distance north or south of the equator is called ***latitude.*** ***North latitude*** is north of the equator, and ***south latitude*** is south of it. The degrees, minutes, etc., are numbered from the equator toward the poles. The latitude of the equator is 0°. Latitude 1° N. is one degree north of the equator, and latitude 90° N. is at the North Pole. Latitude 1° S. is one degree south of the equator, and latitude 90° S. is at the South Pole. If the latitude of a place is 40° 40′ 40″ N., its distance and its direction from the equator are accurately known; but its position on the parallel of 40° 40′ 40″ is not known, for that parallel runs quite around the earth.

Longitude. Position on a parallel is indicated by means of the ***meridians.*** The number of possible meridians is very great, but as in the case of parallels, only a few are commonly shown on maps. One meridian, that passing through Greenwich, England, was long ago chosen as the meridian from which distances east and west are to be reckoned (Fig. 349). This meridian is the meridian of 0°, and is sometimes called the ***prime meridian.*** Distance east or west of this meridian is known as ***longitude.*** Places east of longitude 0° are in ***east longitude***, and those west of it are in ***west longitude.*** East and west longitude respectively are regarded as extending 180° from the meridian of 0°; that is, half-way around the earth.

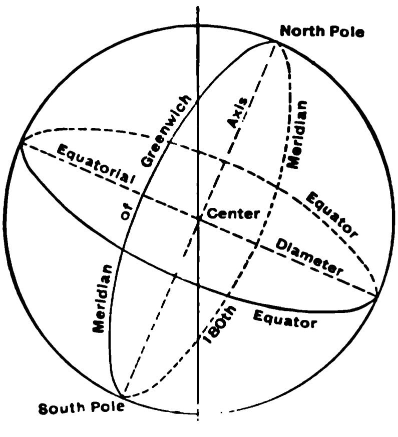

Fig. 349.—Diagram showing the position of the axis of the earth, the poles, the equator, the meridian of Greenwich, and the meridian of 180°.

The position of a place on the earth's surface may be fixed exactly by means of meridians and parallels. If a place is in longitude 30° E., its distance east of the meridian 0° is known. If at the same time it is in latitude 30° N., it must be on the parallel of 30° N. where it is crossed by the meridian of 30° E.

Every meridian passes through each pole. It might seem, therefore, that each pole has all longitude. But longitude is distance east or west of the meridian 0°, and at the North Pole the only direction is south, while at the South Pole the only direction is north. The poles therefore cannot be said to have longitude, since they are neither east nor west of the meridian of 0°.

Longitude and time. There is a definite relation between longitude and time. Since the earth turns through 360° in 24 hours, it turns 15° in one hour, or 15′ of longitude in one minute of time. The sun therefore rises one hour earlier at a place in longitude 0° than in a place in the same latitude in longitude 15° W., and one hour later than at a place in the same latitude in longitude 15° E. Similarly, noon comes an hour earlier in longitude 0° than in longitude 15° W., and an hour later than in longitude 15° E. All places on a given meridian have noon and midnight at the same time, and such places are said to have *the same time;* but places on different meridians have different times. St. Louis is about 15° farther west than Philadelphia, and Denver is about 15° west of St. Louis. When it is noon at Philadelphia it is about eleven o'clock at St. Louis and ten at Denver. When it is one o'clock at Philadelphia it is noon at St. Louis and eleven o'clock at Denver, and when it is noon at Denver it is one o'clock at St. Louis and two at Philadelphia.

The variations of time with changes of longitude become apparent when long journeys are made either east or west. Thus a watch which has the correct time in New York has not the correct time when it is carried to Chicago. To avoid the difficulties of time-keeping growing out of travel, the railroads of the United States have adopted a system of *standard time.* Under this system the country is divided into north-south belts, about 15° wide (Fig. 350), and all places in each belt use the same time. The railway time in adjacent belts differs by one hour. By this system the clocks and watches do not show correct *local* time except on one meridian of each belt.

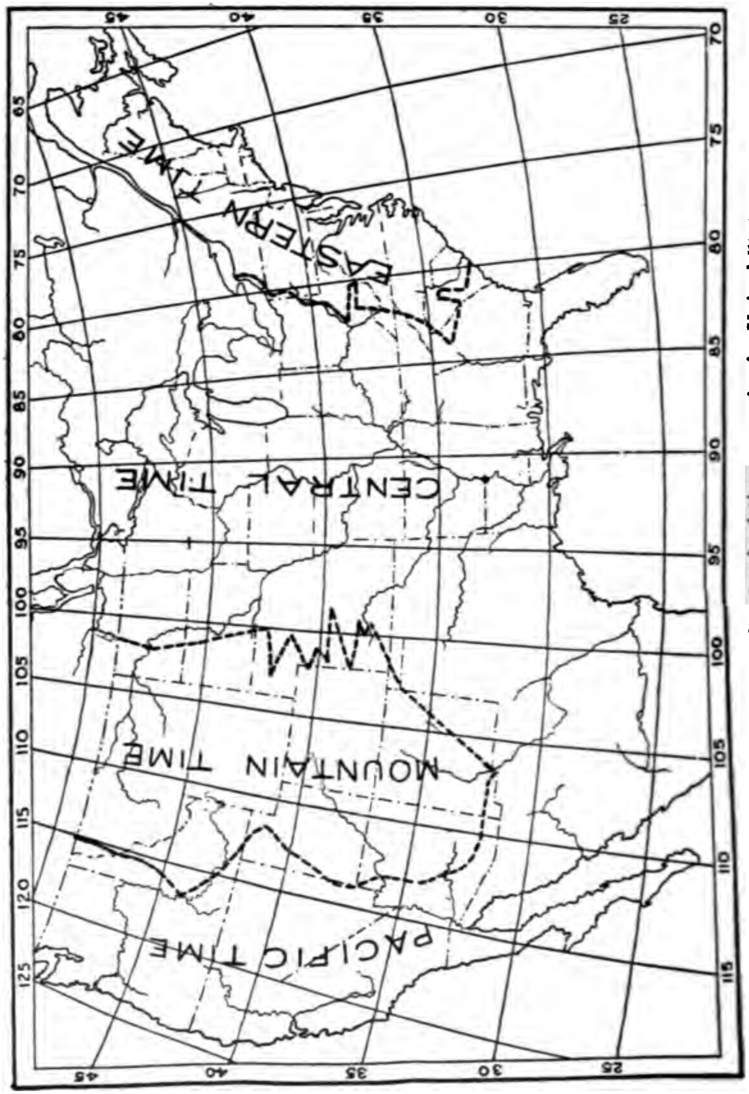

Fig. 350.—Map showing the standard-time zones in the United States.

Lengths of Degrees

The length of a degree of longitude, as measured on the surface of the earth, is the $\frac{1}{360}$ part of a parallel. Since the parallels are very much shorter near the poles than near the equator, the length of a degree of longitude is less in high than in low latitudes. At the poles, where the length of the parallel becomes zero, the length of a degree of longitude also becomes zero. At the equator the length of a degree of longitude is a little more than 69 (69.16) miles.

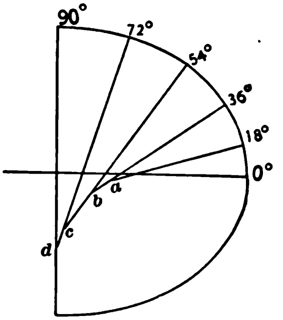

Fig. 351.—Figure to show that the longer degrees of latitude toward the poles means polar flattening. The curve is the half of a spheroid, more oblate than the earth. The radiating lines are represented as 18° apart; that is, the distance from 0° to 18° is $\frac{18}{360}$ of the circle of which an arc of this average curvature is a part. Similarly the distance from 18° to 36° is $\frac{18}{360}$ of the circumference of which a curve of this average curvature is an arc, and so on. The curve between 72° and 90° is much longer than that between 0° and 18°.

Degrees of latitude are measured on meridians. They also vary in length. The length of a degree of latitude is about 68¾ miles in India, while in Sweden, the most northerly point where it has been measured, it is 69¼ miles. All measurements which have been made show that the length of a degree of latitude, measured on the earth's surface, increases as the poles are approached. At the poles it is calculated that it must be about 69⅜ miles. In the United States, the average length is about 69 miles.

The increase of length of the degree toward the poles means that the earth is flattened at the poles. This is shown by Fig. 351. In the study of this diagram it is to be remembered that a degree is $\frac{1}{360}$ *of the angular distance about a point* (say the center of the earth), and, measured on a circumference, it is the $\frac{1}{360}$ part of the circumference described about the point *from which the angle is measured.* Since the degree is longer in high latitudes than in low, it means that the arc on which it is measured is the arc of a larger circle than that on which the degree in low latitudes is measured. In Fig. 351, the center of the circumference on which a high-latitude degree is measured is not the same as the center from which a low-latitude degree is measured.

The actual measurement of the length of a degree of latitude is a difficult matter, but the principle of the measurement is easily understood. At any given point in the northern hemisphere the north star is a certain number of degrees above the horizon. When the observer, starting from any point, has gone northward until this star appears 1° higher above the horizon, he has gone one degree. In practice, the measurement is difficult, for the degree is to be measured at sea-level, and on a smooth surface. Since the land is above sea-level, the actual measurement must be corrected for elevation above sea-level, and for uneveness of surface.

Inclination of Axis and its Effects

The sun's rays illuminate one-half of the earth all the time. The border of the illuminated half is called the *circle of illumination* (Fig. 352). All places on one side of the circle of illumination have day, while all places on the other side have night. If the axis about which the earth rotates were perpendicular to the plane in which the earth revolves about the sun, the circle of illumination would always pass through the poles. Under these conditions, half of the equator and half of every parallel of latitude would be illuminated all the time, as in Fig. 352. If the half of each parallel

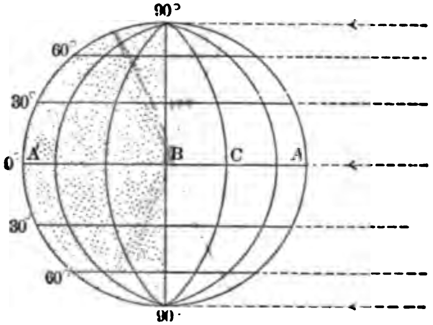

Fig. 352.—Diagram to illustrate the fact that half of the earth is lighted by the sun at any one time. The parallel lines at the right show the direction of the sun's rays. The part of the earth not shaded is lighted by the sun. The other half is in darkness. The line between the illuminated half and the half which is not illuminated is *the circle of illumination.*

was always illuminated, the days and nights would be equal everywhere, for it takes just as long for a place at A (Fig. 352) to move to B (half of a day) as for it to move from B to A' (half of a night).

Since days and nights are not equal at all seasons in most parts of the earth, it proves that the axis on which the earth rotates is not perpendicular to the plane of its orbit.

Again, if the earth rotated on an axis perpendicular to the plane of its orbit, the sun would always be equally high at any given place at the same hour of the day. But this is not the case. In the United States, for example, the sun is much higher above the horizon at noon in summer than in winter. The same is true in all latitudes similar to those of the United States.

This variation of the angle at which the sun's rays strike the earth at a given time and place, as well as the unequal lengths of days and nights in most places, is the result of the inclination of the axis on which the earth rotates as it revolves around the sun (Fig. 347). The position of the axis is constant throughout the year. The effect of the inclination of the axis is illustrated by Fig. 347, which represents the earth in four positions in its orbit. In the position marked March 21st, the half of each parallel (the half toward the reader) is illuminated. At this time, therefore, days and nights are equal everywhere. In the position marked June 21st, more than half (the part not shaded) of every parallel of the northern hemisphere is illuminated, and there the days are more than 12 hours long and the nights correspondingly less. In the southern hemisphere the nights are longer than the days. In the third position, September 22d, the days and nights are again equal everywhere, for the circle of illumination divides every parallel into two equal parts. In the figure the lighted part is away from the reader. In the fourth position, December 22d, more than half of each parallel in the southern hemisphere is in the light, and there the days are longer than the nights, while in the northern hemisphere the nights are longer than the days. Twice during the year, therefore, on March 21st and September 22d, the days and nights are equal everywhere. These times are known as the *equinoxes*. The equinox in March is the *vernal* equinox; that in September is the *autumnal* equinox.

When the earth is in the relation to the sun shown in the position marked June 21st, Fig. 347, the days are longest in the northern hemisphere, and the sun is highest in the heavens at noon, and its

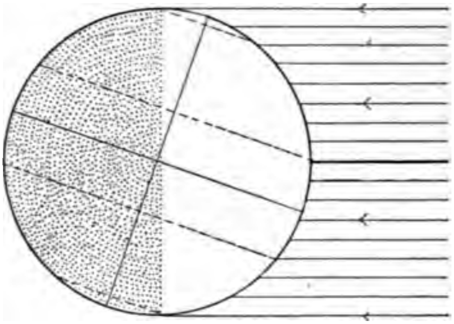

Fig. 353.—Diagram to illustrate the effect of inclination of the earth's axis on the length of day and night. In the figure, more than half of every parallel of the northern hemisphere is illuminated. The days in the northern hemisphere are therefore more than twelve hours long, since the half of each parallel is the measure of 180° of longitude, and 180° of longitude corresponds to twelve hours of time. Similarly less than half of every parallel of the southern hemisphere is illuminated, and the days are therefore less than twelve hours long.

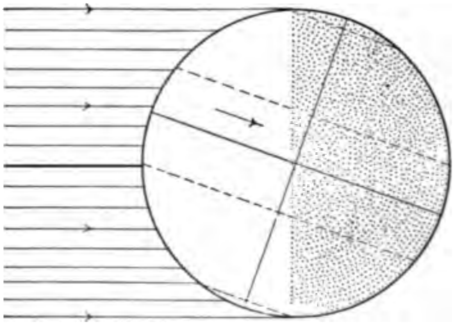

Fig. 354.—The relation of the earth to the sun's rays at a time six months later than that represented in Fig. 353. The conditions of day and night in the hemispheres are reversed.

rays fall perpendicularly on the surface of the earth farther north (23° 27′+) than at any other time. This is the *summer solstice* (Fig. 353). The *winter solstice* occurs six months later, when the sun's rays strike the earth vertically 23½° (nearly) south of the equator (Fig. 354), and when the days of the southern hemisphere are longest and those of the northern shortest. Figs. 353 and 354 also show that the *days and nights are always equal at the equator*, since the equator is always bisected by the circle of illumination. *Days and nights are not always equal in any other latitude*, unless at the poles, where there is one day of six months and one night of six months.

Apparent motion of the sun. The effect of the inclination of the axis of the earth is *to make the sun appear to move north and south* once during each revolution of the earth about the sun. The effect on the earth is illustrated by Fig. 355. That is, the revolution of the earth about the sun, while it rotates on an axis inclined toward the plane of its orbit, makes the sun *appear* to move from a place where his rays are vertical 23½° (nearly) north of the equator (direction *S*, Fig. 355), to a place where they are vertical 23½° (nearly) south of the equator (direction *W*), and back again, in one year.[1] The result, so far as the earth is concerned, is as if

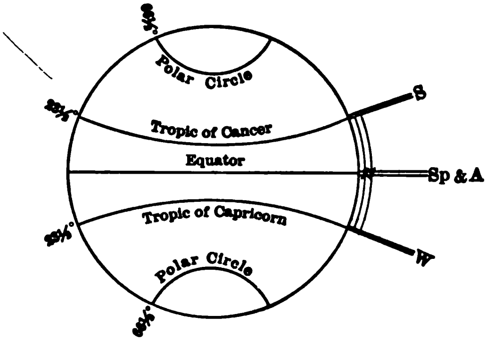

Fig. 355.—The inclination of the earth's axis, as it revolves about the sun, makes the sun appear to travel north and south. The sun is vertical at the equator on the 21st of March (Sp), then appears to move northward until it is vertical 23½° north of the equator (S); it then appears to move southward until it is vertical again at the equator (A), and then 23½° south of the equator (W); it then appears to move north until it is vertical at the equator. These changes are accomplished in the course of one year.

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[1] The inclination of the earth's axis is not quite constant. Its present inclination (1907) is 23° 27′ 5″.

the sun moved from *S*, which corresponds to the time of the summer solstice, to *Sp&A*, which corresponds to the time of the autumn equinox, then to *W*, which corresponds to the time of the winter solstice, then back again to *Sp&A*, which corresponds to the spring equinox, and finally to *S*, while the earth is making one circuit about the sun.

When the sun is vertical at points north of the equator, the days are longer than the nights in the northern hemisphere, and the sun's rays strike the surface in the northern hemisphere more nearly vertically than they do in the southern hemisphere. When the sun is vertical at the equator, days and nights are equal everywhere, and when the sun is vertical south of the equator, days are longer than nights in the southern hemisphere, and the sun's rays are more nearly vertical there than in the northern hemisphere.

The northernmost parallel where the sun's rays are ever vertical is called the *tropic of Cancer.* The corresponding southernmost parallel is the *tropic of Capricorn.* The tropics are nearly 23½° (23° 27′ +) from the equator, because the axis of the earth is inclined by that amount to the plane of its orbit. The sun is vertical at the tropic of Cancer at the time of the summer solstice, and at the tropic of Capricorn at the time of the winter solstice. The parallels just touched by the circle of illumination at the time of the solstices are the *polar circles.* They are as far from the poles as the tropics are from the equator. They are therefore in latitude about 66½°. The one in north latitude is the *Arctic circle,* and the one in south latitude is the *Antarctic circle.*

The Solar System and the Stars

The solar system includes the sun and all the bodies which revolve about it. There are eight planets, of which the earth is one. To us, all the planets except our own appear as stars, but in their motions they behave differently from the other stars. Named in the order of their distance from the sun, commencing with the nearest, the planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Most of the planets have satellites corresponding to our moon.

Besides the planets and their satellites, the solar system includes numerous (more than 400) *asteroids*, bodies much smaller than the planets, intermediate in position between Mars and Jupiter, and those *comets* which revolve about the sun. These bodies have little influence on the earth, and nothing further need be said of them in this place.

The stars, comets, etc. Beyond the solar system there are thousands of stars, each of which may be compared to our sun. We do not know, however, that they have planets circling about them. There are also some comets which do not belong to our solar system.

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PART III

THE ATMOSPHERE

CHAPTER XI

GENERAL CONCEPTION OF THE ATMOSPHERE

Substantiality. When the atmosphere is still we are hardly conscious of its existence, but many familiar phenomena show that the air is very substantial. Thus wind, which is only air in motion, may be so strong that trees and buildings are blown down by it.

The substantiality of the air may be shown in another way. If the air is pumped out of a cylinder whose top is covered by a thin piece of rubber, the rubber cover is pressed down into the cylinder. The force which presses it down is the weight of the air above. This experiment, as well as the strong wind, shows that the air is something real, that it has weight, and exerts pressure. The amount of its pressure, that is, its weight, may be measured. At sea-level it is nearly 15 pounds (14.7) on every square inch of surface.

Relation to the rest of the earth. The atmosphere is often called an *envelope of the earth.* It is, however, a part of the earth, for it goes with the rest of the earth through space, and it is essential to the life of the earth and to most of the processes in operation on the earth's surface. It helps to distribute moisture, and it makes the extremes of heat and cold less than they would be if it did not exist. Without the air, therefore, the conditions on the earth would be very different from what they now are.

The atmosphere is not merely an envelope of the rest of the earth, for it goes down into the soil and rocks as far as there are holes and cracks. Its constituents are dissolved in the waters of the sea also, and in all the waters of the land.

Density. The atmosphere is made up of gases, and the laws which govern the distribution of gases are known. From these laws it is known that the air must be densest at its bottom and less dense above. This is the same as saying that there is more air in a cubic foot of space at sea-level than in a cubic foot of space at higher levels. This means that the particles of which the air is composed are nearer together at low altitudes than at high altitudes.

The reason why air is denser below may be understood readily. If air or any other gas is put under pressure, its particles are crowded together, and it is made denser. At the bottom of the atmosphere the air is pressed down by all the air above, and at the height of 1,000 feet the air is pressed down by all the air above that level, and so on. Hence the lowest air is under most pressure, and this is the reason why it is densest.

It is largely because the air is thin at high levels that mountain-climbing is difficult. As the climber gets higher and higher, it becomes more and more difficult to breathe. He may take in the same number of cubic inches of air each time he inhales, but each cubic inch contains less air the higher he goes. Furthermore, the body is not used to the lessened pressure of the higher altitudes, so that it causes discomfort.

Height. How high above the sea and land does the air extend? No positive answer can be given to this question, though something is known about it.

1. The greatest altitude reached by any mountain-climber is about four and one-half miles. At this height there was still air enough to make breathing possible to a climber. This shows that the air extends to heights of more than four miles and a half.

2. Men have gone up in balloons to heights of nearly six miles. In some cases the men in the balloons have become unconscious at an elevation of about 29,000 feet, and in other cases oxygen has been carried for breathing. Balloons without men have risen ten miles. At this height the air was still dense enough so that the balloon did not sink. This shows that the air extends up more than ten miles.

3. On almost any clear night "shooting stars" may be seen.

These shooting stars, or *meteors*, are small solid bodies which come into the earth's atmosphere from the space outside. They are very cold when they enter the earth's atmosphere, for the temperature of space, outside the earth's atmosphere, is very low (believed to be about –459° F.). In passing through the atmosphere they are heated by friction with the air, and when they get red-hot they glow and may be seen. The height at which they begin to glow has been estimated in some cases, and is found to be, at a maximum, more than 100 miles above sea-level. This shows that the atmosphere is *much more than 100 miles high*, for the meteors *must have come through the rare, cold, upper air a long distance before becoming red-hot.*

4. If we were to go up till half the air is below us, the air at that height should be half as dense as it was at the bottom. If we rise again until half of the upper half of the air is below us, the air at that level is half as dense as it was at the first station. On this principle it would appear that there should be no upper limit; the air should simply get rarer and rarer without having a definite upper surface.

5. All gases have a tendency to fly away from the earth, but are held to it by gravity. Gravity becomes weaker and weaker with increasing distance from the earth's center, and at a sufficient height, the earth would not be able to hold any of the gases of its atmosphere. It is calculated that none of the gases of the atmosphere could be held by the earth at distances greater than 620,000 miles from the center of the earth.

From these considerations it appears to be certain that the air extends much more than 100 miles above the rest of the earth, but how much more is unknown. Whatever its height, one-half the atmosphere (by weight) lies below a plane about 3.6 miles above sea-level, three-fourths of it below a plane 6.8 miles above the same level, and seven-eighths of it below a plane 10.2 miles up. The highest mountain is about six miles high, so that nearly three-fourths of the atmosphere lies below the level of its top.

Volume. Since the height of the air is not known, its volume cannot be determined. If it extends up but 200 miles, its volume is about one-sixth that of the rest of the earth; if it extends up 500 miles, its volume is nearly one-half that of the rest of the earth.

Mass. Great as is the volume of the atmosphere, its mass (measured by its weight) is far less than that of the solid part of the earth, or even than that of the water. It has been estimated at about $\frac{1}{270}$ that of the water, and about $\frac{1}{1200000}$ that of the rest of the earth. Its weight is about equal to that of a layer of water completely covering the earth to a depth of about 33 feet.

History. It is probable that the atmosphere has undergone changes in mass and volume in the course of its history. It was formerly supposed that the atmosphere was gradually becoming less, and that it would, in time, disappear. But this belief does not appear to be well founded. The atmosphere is now gaining various gases from volcanic and other vents (p. 256), and probably has always done so. It is probably getting gases from space also, and though contributions from this source are small now, they may not always have been so. The atmosphere is losing as well as gaining. Some gases, especially light ones like hydrogen, probably escape the attractive control of the earth and pass off into space. Other constituents of the air, especially oxygen and carbon dioxide, are withdrawn from the air and locked up for long periods at least, if not permanently, in the rocks. The rates both of supply and loss vary. When loss exceeds supply, the mass of the atmosphere must decrease; when supply exceeds loss, the mass must increase. It is probable that the variations in composition have been more important than those of mass and volume, at least in the later part of the earth's history.

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CHAPTER XII

CONSTITUTION OF THE ATMOSPHERE

Principal constituents. The composition of the atmosphere is nearly the same at all times and at all places where it has been analyzed. It is made up chiefly of two gases,— (1) *nitrogen,* which makes up about 78 per cent of dry air, and (2) *oxygen,* which makes nearly 21 per cent.

Minor constituents. Beside these two gases, the proportions of which do not vary much, there are several lesser constituents. The most important are (1) *carbon dioxide,* or *carbonic-acid gas,* and (2) *water vapor.* The former makes up about $\frac{8}{10000}$ by weight of the whole atmosphere, and its amount is nearly constant from day to day and from year to year. Water vapor is water in particles so small as to be invisible. The total amount in the atmosphere is not known to vary much, but the amount varies greatly from place to place, and it varies much from time to time in the same place. Since this is so, and since water frequently comes out of the atmosphere in the form of rain, snow, etc., it is often regarded as something in the air, rather than as a part of the air. The weight of the total amount in the air at one time is not known; but it is less than one per cent of the weight of the air, and perhaps not more than one-fifth of one per cent.

Impurities. The air always contains some gases which must be looked upon as impurities, though they are not necessarily harmful to life. Some such gases arise from the burning and decay of organic matter, others from chemical processes used in manufacturing, and still others from volcanic and other vents in the earth's crust. The total amount of gas which enters the atmosphere in this way is small, but in some places, as about some vents, the gases are so abundant as to be injurious to life. This is the case in a valley in the Yellowstone Park, where animals straying into certain places are often killed by the gases.

The air always contains numerous solid particles called *dust*. Though the dust in the air is important, it must be looked upon as an impurity rather than as a constituent.

Relations of gases to one another. The various gaseous constituents of the air are mixed with one another, and each of them retains its own qualities in the mixture. The oxygen behaves as if no nitrogen were present, and the nitrogen as if there were no oxygen.

The Functions of the Atmospheric Elements

The various constituents of the air serve different purposes in the economy of the earth.

Nitrogen is inactive. Though it enters the lungs with oxygen in breathing, it does not appear to be of direct use to animals. Both animals and plants need nitrogen, but few of them are able to use the nitrogen of the air directly. It must first be combined with something else, into *nitrogenous compounds*, from which animals and plants may get the nitrogen they need.

Oxygen from the air is being consumed all the time by all animals. Air-breathing animals take it from the air directly, and water-breathing animals take it from the water in which it is dissolved. Oxygen is consumed by plants also, especially by green plants, and it is used wherever combustion (burning) or decay is going on, for combustion is primarily the union of oxygen with other substances, and decay is very slow combustion. When oxygen enters into combination it loses its distinctive qualities.

In spite of the fact that oxygen is being consumed all the time, its amount does not appear to grow less. We infer, therefore, that oxygen is supplied to the air about as fast as it is used up. The sources of supply are several. Plants break up the carbon dioxide of the air into its elements, carbon and oxygen, and set some of the oxygen free. This is perhaps the greatest source of supply. Oxygen received by the air in this way is not (or may not be) new to it. Much of it at least is only returned to the air, after having been temporarily withdrawn. Oxygen also reaches the atmosphere from volcanic vents, and in other ways.

Though the *carbon dioxide* (CO_2) of the atmosphere is a very minor constituent so far as quantity is concerned, it is most important. We have already seen that it is being constantly produced by the burning of coal, wood, oil, gas, peat, etc., and by the decay of all organic matter. It is also added to the air by animal respiration, and it is poured into the air from volcanic vents, often in great quantities.

From these various sources carbon dioxide is supplied to the atmosphere rapidly. Take, for example, that supplied by burning. About 75 per cent of common bituminous coal is carbon. The carbon of a ton (2,000 lbs.) of such coal, united with oxygen from the air (3 lbs. of carbon unite with 8 lbs. of oxygen), would make about 2¾ tons of carbon dioxide, all of which goes into the atmosphere. A ton of hard coal which contains more carbon, would produce still more carbon dioxide. If we knew the number of tons of coal burned daily, we could calculate the amount of carbon dioxide poured into the atmosphere daily, as a result of its burning. Nearly a billion (1,000,000,000) tons of coal are mined each year, and most of this is burned. When this and all other sources of carbon dioxide are considered, it seems safe to say that carbon dioxide is being supplied to the atmosphere at the rate of several billions of tons per year. Yet the amount of CO_2 in the air does not increase enough to be noted. It must be, therefore, that the CO_2 is being taken out of the atmosphere about as rapidly as it comes in.

Carbon dioxide is taken from the air chiefly (1) by green plants of which it is the chief food, and (2) by combining with mineral matter.

It will be seen that some of the CO_2 is making a continuous round of change. It is taken out of the air by plants, and its constituents, or some of them, become a part of the plant. In this process some of the oxygen is set free in the air. The carbon of the plant is then burned, either in a fire or by decay, and the carbon dioxide gas thus produced passes back into the air, to be used by plants again. Much carbon dioxide goes through this round each year, for much vegetation grown during one growing season is burned or partially decayed before the next.

The various sources of supply of CO_2 are not always equal at the same place, and are not equal at different places. The amount produced by burning is much greater in winter than in summer, but the amount produced by the decay of plant and animal matter is much greater in summer than in winter. Volcanoes are more active at some times than others, and doubtless give forth more CO_2 when most active. The amount produced by animal respiration is probably nearly the same throughout the year.

The rate at which carbon dioxide is taken from the air varies also, since plants use it during the growing season only. Carbon dioxide also enters into combination with mineral matter more readily when it is warm than when it is cold.

At first thought it would seem that carbon dioxide should increase greatly in one hemisphere during the winter season, and decrease in the same hemisphere during the summer; but this is not the case. The reason is twofold. In the first place, the winds distribute the carbon dioxide. In the second place, even without winds the carbon dioxide tends to distribute itself (*diffuse*) equally through the atmosphere.

The supply and loss of carbon dioxide so nearly balance, that no change in the amount of this gas in the air is noted from year to year; but it seems quite possible that in the course of long periods of time the supply may have exceeded the loss, or that the loss may have exceeded the supply.

Small as the amount of carbon dioxide is, it has an important function besides supplying food to plants. The earth is constantly radiating heat into space, somewhat as a hot stove radiates heat into its surroundings, and carbon dioxide has the power of holding much of this heat. It therefore serves as a blanket to hold in the heat of the earth, and thin as the blanket is, it is more effective, in this respect, than the denser blanket of oxygen and nitrogen. If it were thicker, it would be still warmer. If the amount of this gas were doubled, it is thought that the temperature of high latitudes would be notably increased, possibly enough to melt the ice of Greenland.

Water vapor. It has been noted that *the water vapor* in the atmosphere is a variable quantity. It is all the time entering the atmosphere as water vapor, and it is all the time being condensed and precipitated from the atmosphere as rain, snow, etc., to be again evaporated, condensed, and precipitated. Like much of the CO_2, it is making continuous rounds. The amount which the atmosphere may contain at any time depends on temperature; but other things, such as the available local supply, help to determine the amount which there is in the air in any one place. Like the carbon dioxide, the water vapor of the air helps to keep the earth warm.

Dust. All solid particles held in the air are dust. We do not ordinarily see them except on dry, windy days, but dust from the air is constantly settling everywhere, in doors or out, whenever the air is dry. Dust may be readily seen in indoor air if the room is darkened and light allowed to enter through a narrow crack or small hole. Even air which appears clear may in this way be seen to contain countless particles of solid matter. The amount of dust is sometimes very great, as over cities and in dry and windy regions. During the fogs of February, 1891, it was estimated that the amount of dust deposited on roofs in and near London was six tons per square mile. The variety of matter in the dust was great, carbon (soot) being most abundant.

Some years ago a method was devised for counting the dust particles in a given volume of air. The result showed that in the air of great cities there are hundreds of thousands of dust particles in each cubic centimeter (a centimeter is less than four-tenths of an inch) of air; and that even in the pure air of the country, far from towns and factories, there are hundreds of motes per cubic centimeter. It has also been estimated that "every puff of smoke from a cigarette contains about 4,000 million separate granules of dust."[1] The amount of dust in the air is greater over the land than over the sea, and in the lower atmosphere than in the upper.

The dust particles consist of *inorganic materials*, such as (1) tiny particles of mineral matter blown up from dry roads and fields or shot out of volcanoes, (2) particles of smoke from chimneys, and (3) *organic particles*. Among the last are bacteria of various sorts, and the spores of many plants. The number of bacteria found in a cubic meter of air at Montsouris (France) Observatory was 345, while in the same amount of air in the heart of Paris the number was 4,790. These figures give some idea of the relative purity of country and city air. The fact that spores are nearly universal in the air is shown by the promptness with which a moist piece of bread or cake, or a moist piece of leather, gets moldy, especially in a dark place. The molds are plants, and the spores from which they grow were floating in the air, until they found a lodging-place suitable for their growth. In the blossoming season, also, the winds get much pollen dust from flowers. The scattering of pollen by the wind serves an important purpose in the plant world.

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[1] Mill, Realm of Nature.

The dust particles in the atmosphere are important in several other ways. They scatter the light of the sun, so as to illuminate the whole atmosphere. Without the dust in the air, all shady places would be in darkness. The sun would probably appear in dazzling brilliance, shining from a black sky, in which the stars would be visible even in the daytime. The blue color of the sky, and the sunset and sunrise tints, are influenced by the dust in the atmosphere. Dust particles also serve as centers about which water vapor condenses.

CHAPTER XIII

TEMPERATURE OF THE AIR

The temperature of the air varies from season to season, from day to day, and even from one part of a day to another. It is so important in human affairs, that it is convenient to have some easy way of measuring and recording it.

The thermometer. The temperature is measured by means of the *thermometer*, which consists of a glass tube of uniform diameter except for a bulb at one end. The bulb and the lower part of the tube are filled with some liquid, generally mercury, and this is heated until it boils. The boiling expels all air, and while the mercury is boiling, the tube is sealed, the heat being withdrawn at the same moment. On cooling, the mercury in the tube contracts, and fills the lower part of the tube only. Afterward, when the temperature rises, the mercury expands and rises in the tube, and when the temperature falls, the mercury contracts and sinks. The amount of rise or fall of the mercury shows the amount of change of temperature.

A scale is marked on the tube so that the temperature may be read from it. Two scales are in common use — the *Fahrenheit* and the *Centigrade*. The scales are marked on the tube as follows: The thermometer tube is placed in boiling water, or in steam just over boiling water, at sea-level (760 mm. or 14¾ lbs. pressure, see p. 323), and allowed to stay there until the tube and its contents have the temperature of the water. The point to which the mercury rises in the tube under these conditions is marked 212°, if the Fahrenheit scale is to be used. The tube of mercury is then put into pounded ice or snow at a melting temperature, where it remains until the level of the mercury in the tube stops sinking. The level at which the mercury then stands is marked 32°. The space between the 212° mark and the 32° mark is divided into 180 equal parts, each being called a **degree** (1° Fahr.). The marks on the tube may be made for each degree, or for each two, five, or ten degrees.

The space below the freezing temperature also is divided into degrees, each degree below 32° having the same length on the tube as each degree above. The 0° of this scale is 32° below freezing-point. The scale is carried still lower on the tube, and the temperature below 0° is called "below zero." Thus 20° below zero means 52° below the freezing-point, and is written -20° Fahr., or -20° F.

The Centigrade scale is much simpler. The height of the mercury at the boiling temperature of water at sea-level is marked 100° (100° C.), and the freezing temperature under normal atmospheric pressure is marked 0° (0° C.). The space between is divided into 100 parts, each of which is a degree. It will be seen that 1° C. is equal to 1⅘° Fahr. If this is remembered, degrees Farhenheit may be readily changed to degrees Centigrade. The Fahrenheit thermometer is most widely used among English-speaking people, but the Centigrade thermometer is generally used in other countries, and in scientific work, and is in every way better.

The Heating of the Atmosphere

Sources of heat. The atmosphere gets heat from several sources, but that received from the sun (*insolation*) is far greater than that from all other sources.

That much heat is received from the sun is shown by the fact that the temperature generally rises when the sun rises and falls when the sun goes down. It is also shown by the fact that the temperature is generally higher on a sunny day than on a cloudy one. There are some exceptions to these general rules, for now and then a night is warmer than a day, and now and then a cloudy day is warmer than a sunny one of the same season.

The heat derived from other sources is so slight that it may be neglected.

Heating by the Sun, or Insolation

The temperature of space outside the earth's atmosphere is supposed to be about -273° C. (-459° F.), and the warmer temperature which we enjoy at the bottom of the atmosphere is due chiefly to the heat received from the sun. The amount received each year is enough to melt a layer of ice 141 feet thick over the entire earth, or to evaporate a layer of water 18 feet deep.

Each hemisphere receives the same amount of heat each year, but, because of the inclination of the earth's axis, the heat is differently distributed in different latitudes.

1. Other things being equal, the earth gets most heat where the sun shines the greatest number of hours per day. In summer, the days are longest in the highest latitudes. *So far as length of day is concerned*, therefore, the highest latitudes, namely, the poles, should receive more heat than any other part of the earth in summer.

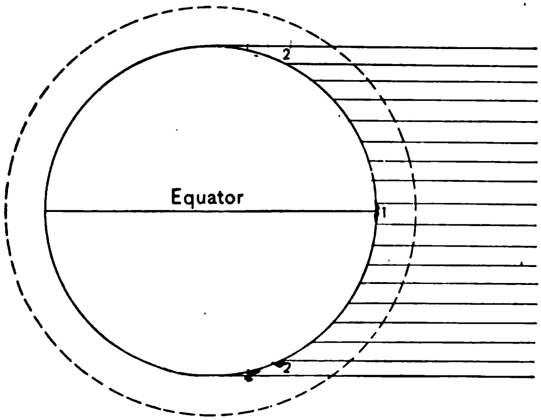


Fig. 356.—Diagram to illustrate the unequal heating due to the direction in which the rays of the sun reach the surface of the earth. The dotted line may be taken to represent the outside of the atmosphere.

2. Other things being equal, the surface of the land or water gets most heat where the sun's rays fall most nearly vertically, because the rays are there most concentrated, and because they pass through a lesser thickness of the air, which absorbs some of their heat. This is shown by Fig. 356. A given bundle of rays, 1, falling vertically on the surface, is distributed over a given space, while an equal bundle of rays, 2, falling obliquely on the surface,

is distributed over a much greater area, and therefore heats each part less. Again, the oblique rays, 2, have passed through a greater thickness of atmosphere, and more of their heat has been absorbed by the air before they reach the surface of the solid part of the earth.

The greater the angle of the sun's rays, the greater the heat. The angle at which the sun's rays reach the earth varies from place to place, and from time to time at the same place. This is a result of the inclination of the earth's axis, and is illustrated by Figs. 347, 353, and 354, which have been explained. In general, low latitudes receive the sun's rays less obliquely than high latitudes.

Primary distribution of heat. It is the rotation of the earth on an inclined axis while it revolves about the sun (Fig. 347) which makes the sun appear to move north and south during the year. From Fig. 355 we see that when the sun sends his rays to the earth from the direction *W* (perpendicular 23½° S. of the equator), they are more oblique than at any other time in the northern hemisphere, and less oblique than at any other time in the southern hemisphere. At this time, therefore, the southern hemisphere is receiving more heat than the northern, because of the lesser obliquity of the sun's rays. At this time, too, the days are longer in the southern hemisphere than in the northern, and this is a second reason why the southern hemisphere is receiving more heat than the northern at this season.

After the time (winter solstice, December 22d) when the sun's rays are vertical at 23½° S, they become perpendicular to the surface in latitudes farther and farther north, and on March 21st they are vertical at the equator. Days and nights are then equal everywhere, because all parallels are cut into two equal parts by the *circle of illumination* (p. 316), and the sun's rays are equally oblique in corresponding latitudes north and south of the equator. Any latitude in one hemisphere is then receiving the same amount of heat as the corresponding latitude in the other hemisphere.

After March 21st, the sun appears to continue its journey northward until June 21st, when its rays are vertical at the tropic of Cancer, 23½° N. The days of the northern hemisphere are then *longest* and the nights shortest, and the rays of the sun are then less oblique in this hemisphere than at any other time. At this time, therefore, the northern hemisphere is being heated more rapidly than at any other.

From June 21st to December 22d, the sun appears to move so that his rays become vertical farther and farther south, and the preceding changes are reversed.

The latitudes where the sun's rays fall vertically range from the tropic of Cancer to the tropic of Capricorn; and the sun's rays are, on the average, least oblique between these limits. This is why the low latitudes are, on the whole, warmer than the high latitudes.

The actual amount of heat received in different latitudes is determined by the length of day (hours of sunshine) and the direction of the sun's rays. It is to be noted, however, that the polar regions, which have the longest days during a part of the year, never have the vertical rays of the sun, or rays which are nearly vertical. The amount of heat received in different latitudes has been calculated. For the year, most heat is received in latitude 0°. Latitude 40° receives about three-fourths as much as the equator, and the poles about half as much. During the half of the year when the sun's rays are vertical north of the equator, March 21st to September 22d, most heat is received in latitude 25° N. Between May 31st and July 16th the North Pole receives more heat than any other part of the earth, the continuous day more than offsetting the great obliquity of the sun's rays at this time (Fig. 353).

The temperature of one place is not necessarily higher than that of another because it receives more heat. No amount of heat, for example, would make Greenland warm until after the snow and ice were melted. The region about the North Pole does not get very warm, even when it receives more heat than the equator, because much of the heat received is expended in melting ice and in warming ice-cold water, which is warmed very slowly, and runs away as soon as the heating is well begun.

Secondary distribution of heat. After the heat from the sun has been received by the earth, it is redistributed to some extent, with the general result that the parts which get more by insolation share their heat with the parts which get less.

There are three ways in which the air receives, loses, and transfers heat. These are *radiation*, *conduction*, and *convection*.

1. *Radiation*. When the sun shines, it radiates heat, and the surface which its rays strike is warmed by absorption of the radiated heat. A body need not be glowing hot, like the sun, or like fire, to radiate heat. Hot water, steam, etc., radiate heat, as in the radiators in our houses. The body which radiates heat is itself cooled. Thus a hot piece of iron soon cools in the air, because it radiates its heat. The land warmed by the absorption of heat radiated from the sun during the day, is cooled by the radiation of its heat during the night. The rate at which a body loses heat by radiation depends upon the difference of temperature between it and its surroundings. A hot stove will cool more quickly in a cold room than in a warm one.

2. *Conduction*. If one end of an iron poker is put in the fire, the other end soon becomes hot. The heat seems to pass along the iron rod from one end to the other. This method of passing heat along is *conduction*. Any cold body in contact with a hot body is warmed by conduction. The bottom of the air is warmed by contact with the land (that is, by conduction) wherever the temperature of the land is higher than that of the air. The hand is warmed by conduction when placed on a piece of metal or wood which feels warm. The hand is cooled by conduction if the metal or wood feels cool.

3. *Convection*. When a kettle of water is placed on a hot stove, the water in the bottom is heated by conduction, that is, by contact with the hot kettle. The heating of the water causes it to expand, and when the water in the bottom of the kettle expands it becomes lighter than the water above it. The heavier water above then sinks and pushes the lighter water below up to the top. This sort of movement is convection. Another illustration of convection is afforded by stoves, fireplaces, and furnaces. A thin sheet of light paper may be held up for a moment by the rising air over a hot stove, or even carried up if the convection current is strong enough. Again, as the air in a chimney is heated, it expands and becomes less dense than the air about it. The cooler, denser air about the base of the chimney or stove crowds in below the expanded air in

the chimney, and pushes it up out of the chimney. Since the air entering the chimney from below is being heated and expanded all the time, the up-draught continues as long as there is fire. Every draught from a chimney is therefore an example of convection.

When the surface of the land is heated by the absorption of heat from the sun, it warms the air above both by conduction and by radiation. The lands of low latitudes are heated more than the others. The heated air over the heated land expands and rises. The beginning of the rise is due to expansion (Fig. 357). If the air in a given region were expanded as shown in Fig. 357, the air at the top of the expanded column would run over, much as water would under similar conditions. *After this takes place,* the amount of air at the base of the column *h* will be less than the amount at the same level outside the heated area, and air from outside the heated column will flow in. This inflow will push up the column of expanded air, and further overflow above will occasion further inflow below. If the heated area continued to be heated, a permanent convection current would be established in the heated area (Fig. 358).

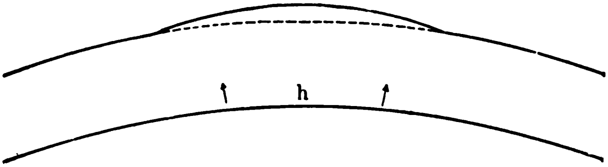


Fig. 357.—The first rise of air, as a result of heating, is due to the expansion of the part heated.

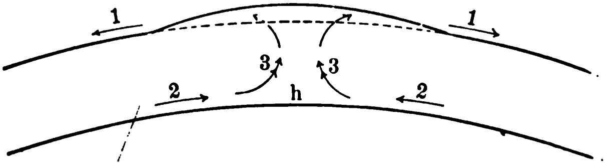


Fig. 358.—The permanent heating of the air over a given region gives rise to permanent convection currents.

It will be noted that convection gives rise to horizontal (Fig. 358) as well as to vertical air movements, and that the horizontal movements take place at various levels.

The atmosphere is heated by the sun in two principal ways: (1) It is warmed by the absorption of the sun's rays as they come through it, and (2) the land and the water are warmed by the absorption of heat radiated from the sun, and they then radiate much of the heat they have received back into the air, thus warming it.

The amount of heat absorbed by the air from the direct rays of the sun depends on the distance the rays travel in the atmosphere, that is, on the obliquity of the sun's rays (Fig. 356). It is therefore different in different latitudes. When the sun is vertical at the equator, the sun's rays pass through about twice as much atmosphere in latitude 60°, nearly three times at much in latitude 70°, and about ten times as much in latitude 85° as they do in latitude 0°. In latitude 70° about half as much heat reaches the surface of the land from the sun as in latitude 0°, when the sun is vertical at the equator.

The heat radiated into the air from below is more readily absorbed by the air than that coming from the sun. The atmosphere is therefore heated by radiation from below more than by direct insolation, and the lower air is heated more than the upper air, because it is denser. On being warmed, whether by conduction or radiation, it gives rise to convection currents which warm the air above.

After the heat is received from the sun, therefore, it undergoes a redistribution. This is accomplished not only by radiation, conduction, and convection, but also by movements of the air (winds) and movements of the water (especially ocean currents). Without these movements of air and water, the average temperature of the equator would be much (perhaps 50° F.) higher than now, and that of the poles much (100° F. or more, estimated) colder.

The heating of land and water. Land is heated four or five times as fast as water by insolation. The reasons are several:

1. A given amount of heat raises the temperature of soil and *rock more* than that of water.

2. Water is a good *reflector*, while the land is not, and the latter, therefore, absorbs a larger proportion of the heat of the sun's rays.

3. Convection movements are established in water as soon as its surface is heated locally. This prevents excessive heating at any one point. The land, on the other hand, being solid, is without movements of convection.

4. There is more evaporation from a water surface than from land surface, other conditions being the same, and evaporation cools the surface from which it takes place.

5. Light and heat rays penetrate water, but not soil and rock to any considerable extent. The heat of insolation is therefore distributed, at the outset, through a greater thickness of water than of soil. Being confined to the surface of the latter, its temperature is made higher.

THE SEASONS

We are now prepared to understand the seasons, and the reasons for their differences of temperature. In most latitudes, the seasons are usually said to be four — spring, summer, autumn, and winter. Each grades into the one which follows.

In the United States, March, April, and May are commonly called the spring months, June, July, and August the summer months, September, October, and November the autumn months, and December, January, and February the winter months. In the southern hemisphere spring comes in September, October, and November, summer in December, January, and February, and so on. The vernal equinox of the northern hemisphere is the autumnal equinox of the southern, and the summer solstice of the northern is the winter solstice of the southern. This subdivision is based on temperature, the summer being made up of the three warmest months, so far as intermediate (temperate) latitudes are concerned, and the winter of the three coldest.

The seasons are sometimes defined in a different way. Thus spring is sometimes regarded as the time between the vernal equinox and the summer solstice; summer the time from the summer solstice to the autumnal equinox, etc.

In middle latitudes we think of the difference between seasons as one of temperature; but in some parts of the earth, *wet* and *dry* seasons are more distinct than *warm* and *cold* ones. In the polar regions the temperature of the cold season is very much lower than that of the warm one, but there is also a striking difference in the matter of light. The warm season is the *light* season, and the cold season is the *dark* one.

Differences between summer and winter. Summers and winters differ in ways other than temperature. Some of them are the following: (1) In our latitudes the summer days are more than 12 hours long, and the nights less. (2) The sun is much higher above the horizon at noon in summer than at noon in winter. This is the same as saying that the sun's rays are less oblique in summer than in winter (Figs. 353 and 354). (3) In summer the sun rises to the north of east and sets to the north of west, while in winter it rises to the south of east and sets to the south of west. (4) The amount of moisture in the air often varies with the season; but in some regions it is the warm season which is wet, while in others it is the cool season. (5) In some regions the winds change their direction and force with the change of seasons, as will be seen later. The first and second of these differences are the most important, so far as concerns the seasons of middle latitudes.

Why we have summer when we do. (1) Long days and short nights give more hours of heating than of cooling each day, while short days and long nights mean fewer hours of heating and more hours of cooling. (2) The sun's rays are less oblique when the days are long (Fig. 353, northern hemisphere), and so have greater heating power. In summer, therefore, the surface is heated more hours a day than during the winter, and the average amount of heat per hour is greater while the sun shines. These are the chief reasons why summer is warmer than winter.

The reasons why the days are longer at one time of the year than another have already been given (p. 317). Most of the differences between summer and winter, besides those of temperature, depend upon differences in temperature.

Change of seasons. We have already seen (1) that the sun's rays are vertical at the equator at the time of the equinoxes (March 21st and September 22d), and that the days and nights are then equal everywhere; (2) that the northern hemisphere is being heated most by the sun at the time of the summer solstice, and least at the time of the winter Dec 22 solstice, (3) that the days are longer than the nights in the northern hemisphere from March 21st to September 22d, (4) that the sun's rays are less oblique in either hemisphere during the half of the year when the days are longer than the nights, and (5) that the relative lengths of day and night and the angle of the sun's rays are reversed in each hemisphere every half-year. These points are illustrated by Figs. 353 and 354.

Times of greatest heat and cold. Since the northern hemisphere is being heated most at the time of the summer solstice and least at the time of the winter solstice, it would seem at first thought that these dates, respectively, should be the times of greatest and least heat; but this is not the case. It follows that the temperature of any given latitude is not altogether dependent on the amount of heat it is receiving from the sun. Again, since all latitudes in the two hemispheres are being heated equally at the equinoxes, it would seem, at first, that corresponding latitudes in the two heimspheres should have the same temperature at these times; but this, again, is not the case. In our own latitude, for example, March 21st is much colder than September 22d.

The reason why a place in our latitude is warmer at the time of the autumnal than at the time of the vernal equinox is because the warmth of the summer just past has not all been lost. The soil, the surface rocks, the lakes, etc., have all been warmed during the summer, and they cool slowly. At this time, therefore, the northern hemisphere has a temperature higher than that which it would have if it depended entirely on the heat received from the sun each day. On the other hand, the temperature at the time of the spring equinox is lower than that which the daily heating would seem to produce, because the cold of the winter just past has not been altogether overcome. In middle and high latitudes, snow and ice cover land and water to some extent, and the water in the ground is still frozen. This keeps the lower part of the air cool. The cold of the spring is rather more enduring than the heat of the autumn.

The summer solstice is not the hottest part of the year in the northern hemisphere, for the summer's heat has not altogether overcome the effect of the preceding winter. *The time of greatest heat lags behind the time of greatest heating.* In middle latitudes the lag is about a month, but it is more over the ocean than over the lands, because land is heated and cooled more readily than water (p. 340). Similarly the time of greatest cold does not come till after the time of least heating.

Seasons in other latitudes. The seasons in some other latitudes are unlike our own. At the equator, for example, the sun's rays are vertical twice each year, at the time of the equinoxes. Twice a year, too, the sun's rays are vertical 23½° from the equator, once to the north and once to the south. The equator, therefore, has two seasons, occurring at the time of our spring and autumn, which are somewhat warmer than two other seasons occurring at the time of our summer and winter. The variations in temperature are much less than in our own latitude, for the length of day and night never varies at the equator, and relatively little in the tropics, and the angle of the sun's rays varies less than with us. At the equator, therefore, there is a fourfold division of the year, but the differences in temperature are far less than in our latitudes.

In high latitudes the conditions are still different. In latitude 60°, for example, the differences in the seasons are similar to those of the central part of the United States, except that the differences between summer and winter are greater. This is because of the greater difference in the length of day and night (Fig. 359).

The change of seasons in latitude 75° N. may be taken to illustrate the conditions in latitudes above the polar circle. When the sun's rays are vertical 15° south of the equator (*D*, Fig. 359), the sun appears on the horizon at noon in latitude 75° N., for this latitude is 90° from the place where the sun's rays are vertical. When they are vertical farther south than 15° S., points on the parallel of 75° N. do not see the sun (Fig. 359). When the sun's rays are vertical in latitude 15° N. (*B*) or in any latitude farther north, no point on the parallel of 75° N. will be in darkness during any part of the twenty-four-hour day. When the sun's rays are vertical in any latitude between 15° S. and 15° N., a part of the

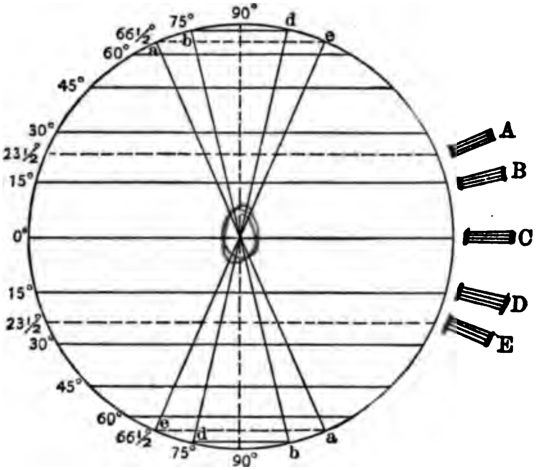


Fig. 359.—Diagram to illustrate seasons in latitude 75°. When the sun's rays are vertical at *C*, the circle of illumination is represented by the line 90° -90°. The half of each parallel of 75° is then illuminated, and days and nights on that parallel are therefore equal. The same is true of all other latitudes. When the sun's rays are vertical at *B*, in latitude 15° N., the circle of illumination is represented by *b b*, the whole of the parallel of 75° N. is illuminated, and daylight is continuous throughout the twenty-four hours. No part of the parallel of 75° S. is illuminated at this time, and on that parallel darkness is continuous. When the sun is vertical at *A*, in latitude 23½° N., the circle of illumination is represented by *a a*. While the sun appears to move from position *B* to position *A* and back again to *B*, the parallel of 75° N. is continuously illuminated, while the parallel of 75° S. at the same time is continuously in darkness. When the sun appears to move from the position where its rays are vertical at *B* to the position where its rays are vertical at *D*, a part of each parallel of 75° is illuminated, and during this time, therefore, there is light and darkness in the course of the twenty-four hours. When the sun's rays are vertical between *B* and *C*, more than half of the parallel of 75° N. is illuminated, and less than half of the parallel of 75° S. When the sun is vertical at *C* the half of each parallel of 75° (and of all other parallels) is illuminated, and days and nights are equal everywhere. While the sun appears to pass from *C* to *D* less than half of the parallel of 75° N. is illuminated, and more than half of the parallel of 75° S. During this time, therefore, nights are longer than days in latitude 75° N., and days are longer than nights in latitude 75° S. When the sun is in a position where its rays are vertical at *D*, the circle of illumination is *d d*. At this time all of the parallel of 75° N. is in darkness, and all of the parallel of 75° S. is in light. This condition continues while the sun appears to move from the position where its rays are vertical at *D*, to the position where its rays are vertical at *E*, and back again.

parallel of 75° N. will be lighted, and all points on that parallel have alternating light and darkness in the course of twenty-four hours.

In latitude 75° N. there is a natural fourfold division of the year, one (summer) when daylight is continuous, one (winter) when darkness is continuous, one (spring) when there is alternating day and night, with the days lengthening, and one (autumn) when there is alternating day and night, with the nights lengthening. According to this subdivision of the year, summer is the time during which the vertical sun appears to move from 15° N. to 23½° N. and back again to 15° N. Autumn is the time during which it appears to pass from the position where its rays are vertical 15° N. to the position where its rays are vertical 15° S. Winter is the time when it appears to pass from 15° S. to 23½° S. and back again to 15° S., and spring the time when it is passing from 15° S. to 15° N.

It will be noted that the lengths of the seasons defined in this way are not the same. In latitude 75° the summer would be as long as the winter, and the spring as long as the autumn; but the spring and autumn would be nearly twice as long as the summer and winter, for during each of the former the sun moves through 30°, and during each of the latter, 17°. Not only this, but the lengths of the several seasons would vary with the latitude. In latitude 85° the summer and winter would be longer than in latitude 75°, and the springs and autumns shorter.

There is a common idea that in polar regions there is a day of six months and a night of six months each year, but this notion is not correct. *There is a six-month day and a six-month night at the poles only.* This can be worked out from Fig. 359.

Effect of varying distance of the sun. Since the orbit of the earth is an ellipse (Fig. 346), the distance of the earth from the sun varies in the course of a year. The earth receives more heat daily when it is nearer the sun, and less when it is farther from it; but these variations in the amount of heat are of little importance. At the present time, the northern hemisphere has its summers when the earth is farthest from the sun, and its winters when it is nearest to it.

Effect of Altitude on Temperature

High altitudes are colder than low ones in the same region. Thus mountains are always colder than the plains about them. The average decrease of temperature is about 1° F. for 330 feet (1° C. for 594 feet) of rise, for the altitudes where observations are common. One mile of rise in the air means about the same decrease of temperature as a journey of 1,000 miles toward the poles.

When air rises it expands, because there is less weight of air above it, and as a gas expands it is cooled. Dry air is cooled about 1° F. for every 183 feet it rises (1° C. for 329 feet); moist air cools much less rapidly, for reasons which will appear later. When air descends it becomes denser and warmer.

The temperature has been observed in balloons up to elevations of about 30,000 feet, where it was found to be –54° F. It has been recorded by self-registering thermometers in balloons sent up 10 miles, where the temperature was –104° F.

High altitudes are colder than low because the air is thinner. Since it is thinner, it absorbs less heat from the direct rays of the sun, and it holds less of the heat radiated from the earth below.

The temperature over land 10,000 feet high is not the same as the temperature of the air 10,000 feet above sea-level. Land surfaces at high altitudes may be heated quite as much by the sun as those at low altitudes; but since the air over the high land is thin, it does not hold the heat radiated from the land so well as denser air would. The result is that both the air and the land of high altitudes cool faster than those of low altitudes, and this makes the average temperature of high altitudes lower.

Isolated elevations like mountain-tops are colder than plateaus of the same elevation, because they are so well exposed to cooling. In sunny days in summer, the sunny side of a mountain free from snow gets very warm (Fig. 360). If the rock is bare it may become so hot that the hand cannot be held on it. If the air remained long in contact with such a rock surface it would be warmed to the same temperature; but it is commonly moved on quickly by winds before it gets very warm, and its place is taken by colder air. Again, an isolated mountain-peak radiates heat in all directions except downward, while a flat surface radiates it upward only. In mountains, too, there are likely to be many cloudy days, and the clouds shield the rocks from the sun. This tends to lower the *average* temperature of the mountain, as compared with that of low land.

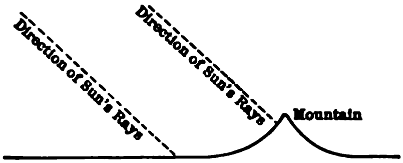


Fig. 360.—Diagram to show that the sun's rays may fall less obliquely on a mountain slope than on the plain adjacent. Under these circumstances they have greater heating power, so far as the surface of the land is concerned, on the mountain than on the plain.

Where mountains are sufficiently high, and not too steep to retain snow throughout the year, *their surfaces are never warmed above a temperature of 32° F.*, the melting temperature of snow. All the heat received beyond that necessary to raise them to this temperature is spent in melting and evaporating snow, not in raising the temperature of its surface. It is to be especially noted that the air over the heated rock of high altitudes, whether of mountain or plateau, does not get so warm as the rock itself. The difference between the temperature of the rock and that of the air above it in such situations is very great when the sun shines.

Representation of Temperature on Maps

It is desirable to have some method of representing the temperature of all parts of the earth on maps. Maps showing the distribution of temperature are *thermal maps*.

Lines may be drawn on the surface of the earth, connecting points having the same temperature. Such lines are ***isotherms***. An isotherm connecting places having the same average temperature for the year is an *annual isotherm*. Fig. 361 shows a very simple isothermal chart for the year, the isotherms of 0° F., 30°, 50°, and 70° only being represented. An isotherm connecting places which have the same summer or the same winter temperature is a *seasonal isotherm.* Isotherms may be drawn for a month or for any other specified period of time. A map showing isotherms is an *isothermal map,* and an isothermal map should always tell whether the isotherms are annual, seasonal, or monthly.

Pl. XXII shows annual isotherms for each 20° F. At the extreme north there is the isotherm of 0° F., which lies north of Europe and Asia, and barely touches North America. The average annual temperature of places on this line is 0° F. The isotherm of 10° F. lies south of the isotherm of 0° F. The average temperature of places between these two lines is more than 0°, and less than 10°. South of the isotherm of 10° follow in order the isotherms of 30°, 50°, 60°, and 70°, the last being everywhere below the latitude of 40° N.

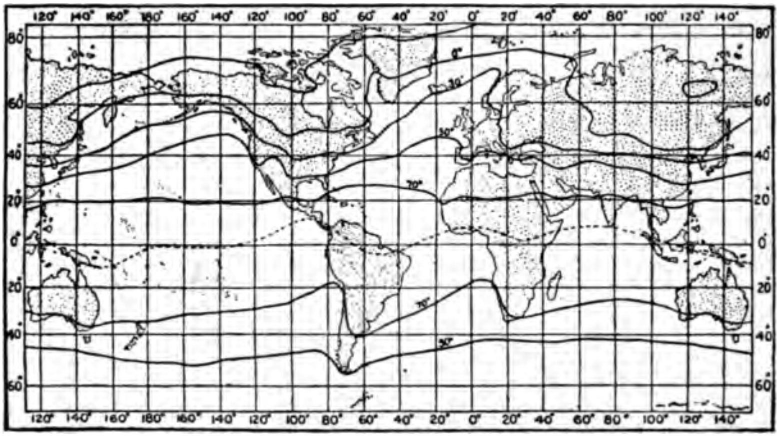


Fig. 361.—Chart showing a few isothermal lines. The dotted line near the equator represents the position of the heat equator.

The coldest isotherm shown on the chart in the southern hemisphere is that of 30°, lying south of all lands except Antarctica. The latitude of this isotherm corresponds nearly to the latitude of the isotherm of 30° in the northern hemisphere. Next north (toward the equator) of the southern isotherm of 30° is the isotherm of 50°, followed by those of 60°, and 70°, the last being everywhere north of latitude 40° S.

In the Pacific Ocean, except at the west, there is no isotherm between that of 70° in the northern hemisphere and that of 70° in the southern hemisphere. Where the isotherm of 80° does not appear between the two isotherms of 70°, the temperature is warmer than 70°, but nowhere so warm (on the average) as 80°. In the Americas, and farther east, there are two isotherms of 80° between those of 70°. Between the two isotherms of 80° the temperature is, on the average, warmer than 80°, but not so warm as 90°. If it had been so warm as 90°, the isotherm of 90° would have been shown.

The line of highest temperature about the earth is the *thermal equator* (the broken line, Fig. 361). The thermal equator does not follow a straight course around the earth, and it lies a little north of the geographic equator.

Pl. XXII shows that the annual temperature is highest near the equator, and that it becomes lower toward the poles. This shows that there is some relation between isotherms and latitude, and the explanation of this relation has been given.

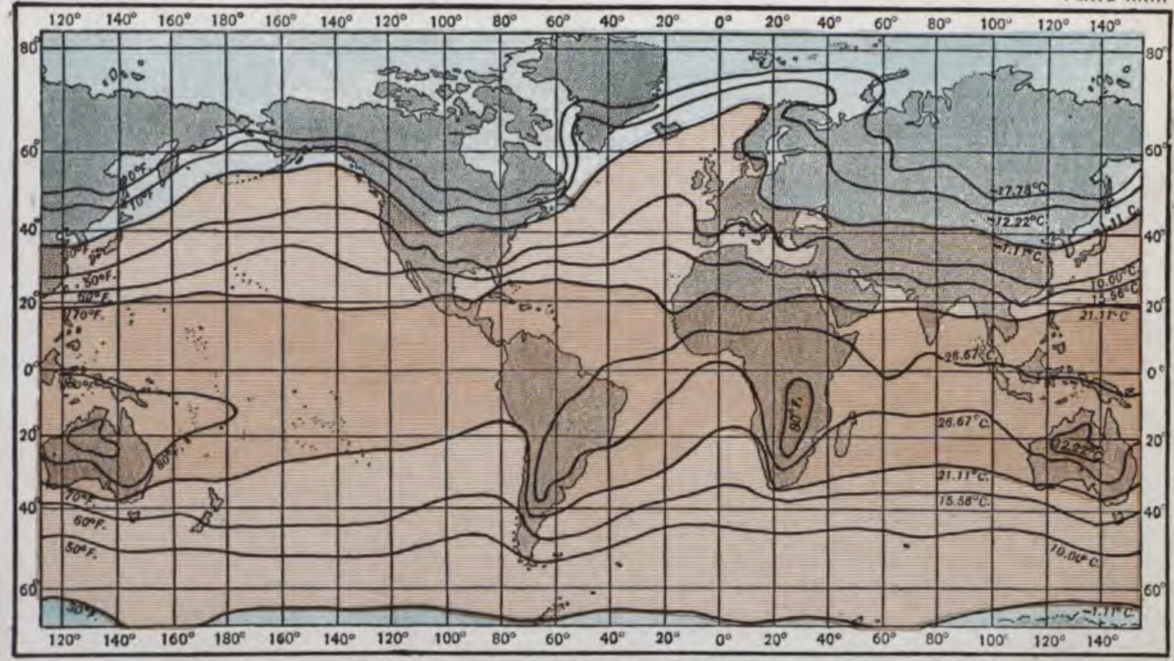
Pl. XXIII shows the isotherms for the month of January. On this chart all isotherms are farther south than on the chart showing the annual isotherms. Thus the isotherm of 0° F. (17.78° C.) in the northern hemisphere runs through central Asia, instead of lying north of it, and the isotherm of 60° is everywhere south of latitude 40°, instead of being partly north of it, as in Pl. XXII. At this time of the year the sun is shining vertically south of the equator, and this seems to be a sufficient reason for the change.

Pl. XXIV shows the isotherms for July. All isotherms are farther north than the corresponding ones on either of the other charts. Thus the isotherm of 50° in the northern hemisphere is about where the isotherm of 20° was in January (Pl. XXIII).

Comparing Pls. XXIII and XXIV, it is seen that the difference of temperature between January and July is much greater in high latitudes than in low. Thus in the southern part of Hudson Bay there is 70° difference between January and July; at Lake Erie, about 45°; in Florida, about 20°; and at the equator in South America, less than 10°.

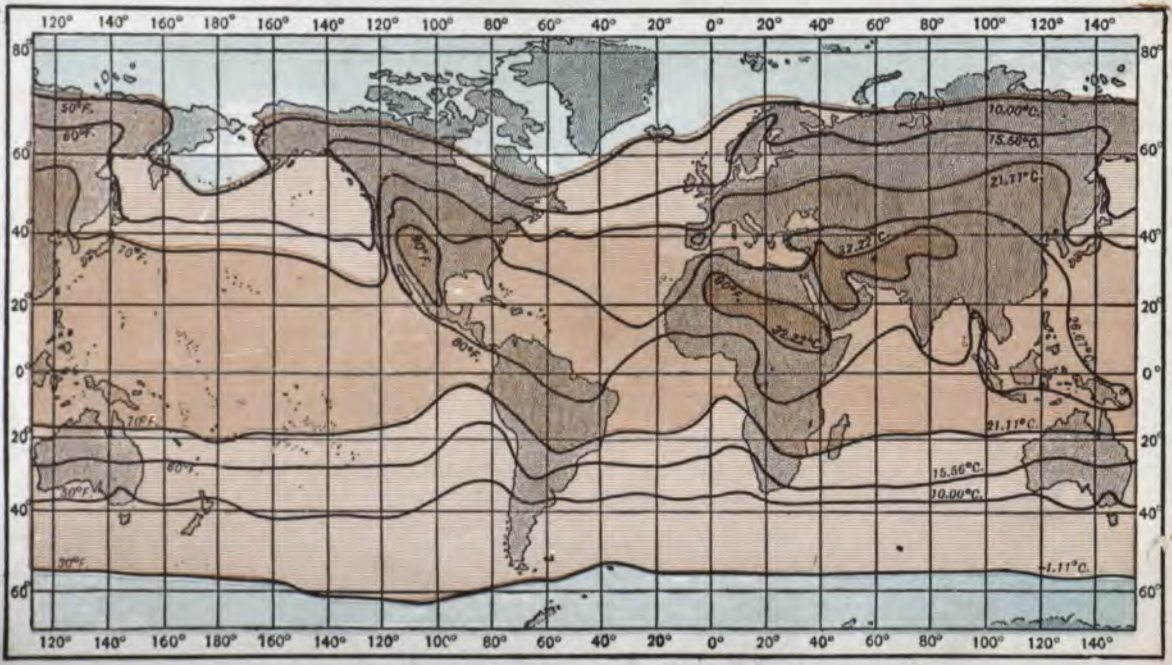
The same charts show that the difference is greater in the

PLATE XXIII



Isothermal chart for January. (After Buchan.)

PLATE XXIV



Isothermal chart for July. (After Buchan.)

interiors of continents than on coasts or over the sea in the same latitude. Thus in the interior of North America, west of Hudson Bay, the difference is about 80°, while on the coast of Alaska it is only about 30°. In northern Asia the difference is 70° F. or more, while in Scandinavia it is but about 30°.

The courses of the isotherms. 1. The courses of the isotherms are, in a general way, east-west; that is, they are roughly parallel to the parallels of latitude. Some of them are very irregular, it is true, but the east-west direction is the most common one. This shows some relation between the courses of isotherms and latitude; but since the isotherms do not follow the parallels exactly, it is clear that latitude is not the only thing which determines their position. It follows that some cause or causes besides the length of day and the angle of the sun's rays must influence temperature, and so the position of the isotherms.

2. Pls. XXIII and XXIV show that the isotherms are straightest where there is little land, and most crooked where there is much land. This suggests that the *land and water* have something to do with their positions. There are various irregularities in the isotherms on land that do not appear on the sea. Thus, on the January chart there is an area in south Africa, and another in Australia, surrounded by the isotherm of 90°, and there are similar areas in North America, north Africa, and southern Asia, in July. All of these areas are on land. These facts tend to confirm the conclusion that the sea and the land influence the position of the isotherms.

Following this idea still further, it is seen that the isotherms of January frequently bend somewhat abruptly in passing from water to land, or from land to water. Thus the isotherm of 30° in the northern hemisphere turns to the south when it reaches North America, and again on the coast of Europe. In the southern hemisphere the isotherms of 80° and 70° make abrupt turns at the west coast of Africa, and the isotherm of 70° near the west coast of South America. These bends at the coasts give further support to the conclusion that the distribution of land and water have something to do with the position of isotherms.

It has been noted already (p. 340) that the land is heated and cooled more readily than the sea, and is therefore colder in winter and warmer in summer. The January isotherm of 30° in the northern hemisphere bends toward the equator in crossing the northern continents, because the land is cooler than the water in the same latitude at this time of year. In the southern hemisphere, on the other hand, where it is summer, the isotherms bend toward the pole on reaching the land, because the land is warmer than the sea in the same latitude.

The chart of the July isotherms leads to the same conclusion. On this chart the isotherms crossing the northern continents bend poleward on the land, while those crossing the southern continents bend equator-ward. The reason is that this is the season when the lands of the northern hemisphere are warmer than the seas of the same latitude, and when the lands of the southern hemisphere are cooler than the seas about them.

The irregularities of the isotherms of the northern hemisphere in July are much greater than those of the southern hemisphere in January (summer in the southern hemisphere). This is probably because there is much more land in the northern hemisphere than in the southern, and the larger land areas have a greater effect on the isotherms than the smaller ones. All these features of the isothermal maps indicate clearly that land and water influence the position of the isotherms.

3. There are some features of the isothermal lines which are not explained by latitude, or by the distribution of continents and oceans. Thus the bends of the isotherms are not as pronounced on the east sides of the continents as on the west. This is shown by Pls. XXIII and XXIV. Again, traced eastward, the January isotherm of 40° bends southward near the west coast of North America *on the land,* while on the eastern side of the continent it bends northward *on the sea,* not on the land. Such peculiarities may be explained by the *winds.* The prevailing winds in the middle latitudes of North America are from the west, and the westerly winds tend to carry the temperature of the sea (warmer in winter) over onto the land on the western side of the continent (Pl. XXIII), and the temperature of the land (cooler in winter) over onto the sea, on its eastern side. This explains the bends of

the isotherm of 40° near the coasts in the northern hemisphere in January.

4. The great bend in the isotherm of 30° in the North Atlantic in January is not explained by the relations of land and sea, or by winds. It is due to a warm current of ocean water flowing northeastward, in the direction of the pronounced loop of the isotherm. *Ocean currents* are therefore a fourth cause of the irregularities of isotherms.

The amount of heat carried northward by the ocean currents of the Atlantic and Pacific is very large. It has been estimated that the temperature of England and Norway is raised several degrees by the warm poleward movement of waters in the North Atlantic. The temperature of the land is warmed by this water, because the air over the warm ocean water is warmed and then blown over the land.

The milder climate of northwestern Europe, as compared with northeastern North America, is not due wholly to the northward movement of warm water. Even without such movement the climate of northwestern Europe would be more temperate than that of northeastern North America in the same latitudes, because the ocean, from which the winds of winter blow to that part of Europe, is warmer than the land whence the winds blow to the lands of the same latitude on the west side of the Atlantic.

5. There are some other causes of irregularities in the isotherms. Thus a basin region, shut in by mountains, gets hotter in summer than a region not so surrounded. This is partly because the air is warmed by heat reflected and radiated in from the mountains on all sides, and partly because the enclosing mountains prevent free circulation of the air.

6. Again, there is less evaporation from a dry surface than from a moist one, and since evaporation cools the surface, a dry surface will be warmer than a moist one if other conditions are the same. The color of the soil, the presence or absence of vegetation, etc., also affect the absorption and radiation of heat.

The high temperature (90° and above) in the southwestern part of the United States in July is accounted for partly by the fact that the region is somewhat shut in by mountains. The dryness of the soil and of the air above it also tend to raise its temperature. Aridity also helps to make the temperature high in northern Africa in July, and in Australia in January.

Altitude affects temperature, as already explained, but isothermal charts show no relation between isothermal lines and surface relief. The reason is that isothermal lines are represented on maps as if they were at sea-level. This is done by making allowance for altitude at the average rate of 1° F. for about 330 feet. Thus if the temperature of a place at an altitude of 3.300 feet is 60°, it is put down on the chart as 70° (60°+10°). If the place were 6.600 feet above sea-level, 20° F. would be added to the temperature recorded by the thermometer. Isothermal charts, therefore, are intended *to show the temperature as it would be if the land were at sea-level.*

Isothermal surfaces. A surface might be drawn connecting all points having the same temperature. The annual isothermal surface of 30°, for example, would be at sea-level where the isotherms of 30° appear in Pl. XXII. One of these isotherms is north of the equator, and one south of it. Equator-ward from these lines, in either hemisphere, the isothermal surface of 30° would rise above sea-level. The temperature at sea-level in the northern part of South America is about 80° (Pl. XXII). Its temperature is therefore about 50° above that of the isothermal surface which we wish to represent. To find the isothermal surface of 30° here, we should have to rise far above sea-level. Where the isotherm of 50° crosses North America, the temperature at sea-level is about 20° too high. To find the temperature of 30° in this latitude, we must rise high enough into the air to get a reduction of 20°.

North of the isotherm of 30° in the northern hemisphere (Pl. XXII) the temperature at sea-level is less than 30°. To find a temperature of 30° in this latitude, therefore, we must go beneath sea-level.

The proper conception of isothermal surfaces will be of importance when we come to consider the circulation of the atmosphere.

Daily Range of Temperature

The temperature of the day when the sun shines is generally *warmer than* the temperature of the night. The difference between the temperature of night and day is often as much as 40° or 50° F. in dry, interior regions, and in the Sahara it is sometimes 70°. The daily range is greater when the air is dry than when it is moist, and it is greater far from the sea than near it. Other things being equal, the daily range is greatest when days and nights are nearly equal. The daily range is less above the bottom of the atmosphere than at the bottom, since the lower air is heated much by contact with the land during sunny days.

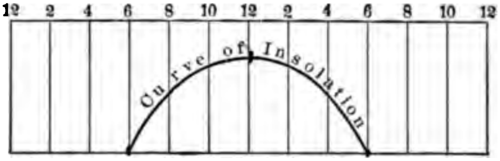


Fig. 362.—Curve of insolation. Insolation begins at sunrise, which, according to the figure, is at six o'clock in the morning, and ends at sunset, at 6 in the evening.

Let us suppose a day (hours of sunshine) of 12 hours. When the sun rises the daily heating begins, and increases as the sun gets higher. Most heat is received when the sun is highest; that is, at noon. The heating becomes less and less, as the sun get lower, and at sunset it stops altogether. Fig. 362 shows the curve of insolation.

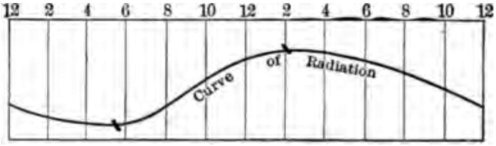


Fig. 363.—Curve of radiation. The surface of the land radiates heat most rapidly when it is warmest, and least rapidly when it is coolest. The surface is coolest about sunrise. Heat is then radiated least rapidly, but the rate of radiation increases as the day advances, and reaches its maximum about three o'clock. Later in the day, as the temperature decreases, the radiation also decreases and becomes less and less until the next sunrise.

The land and the air just over it are cooled by radiation all the time. When cooling by radiation exceeds heating by insolation, the temperature falls. This is the case, as a rule, at night, for radiation goes on after insolation ceases. The temperature becomes lowest about sunrise, when radiation without insolation has been going on longest. The land and the lower air continue to radiate heat after sunrise, but both are then heated, and heated as a rule faster than they are cooled by radiation, for the temperature rises. As the temperature rises radiation increases (Fig. 363); but it does not commonly keep pace with insolation, for the temperature continues to rise till some time after noon. The fact that the temperature then begins to fall shows that radiation then exceeds insolation. Fig. 364 shows the curve of insolation in its relation to the curve of radiation.

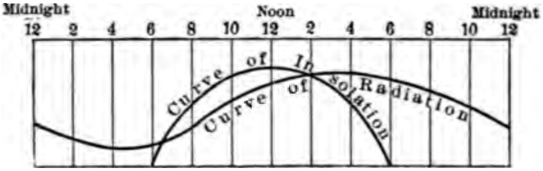


Fig. 364.—Curves of insolation and radiation combined. The maximum temperature of the day occurs at the higher crossing, the minimum temperature of the day at the lower crossing of these two lines.

Seasonal range of temperature. The seasonal range of temperature is affected by (1) latitude, (2) position with reference to land and sea, (3) prevailing winds, and (4) the presence of snow during the warmer season.

1. The seasonal range of temperature increases with the latitude (compare Pls. XXIII and XXIV), because the yearly variation in insolation increases with the latitude. This range is greatest at the poles where there is six months of insolation and six months without it. The great range of seasonal temperature to which the poles would be entitled by their latitude is greatly modified by the conditions mentioned under (2) and (4) above.

2. Islands have a lower range of temperature than continental lands in the same latitude, and coasts have a lower range than interiors, because the range of sea temperature is less than the range of land temperature (Pls. XXIII and XXIV).

3. A coast to which the prevailing winds blow from the ocean. *has a less range* of temperature than a coast to which the prevailing

winds blow from the land. Thus the range of temperature is less on the Pacific coast of the United States than on the Atlantic in the same latitude (Pls. XXIII and XXIV), the winds being chiefly from the west in both cases.

4. The presence of snow during the warm season, as in high latitudes and high mountains, prevents a high temperature in summer, even though insolation is strong (p. 348).

The annual range of temperature has some effect on vegetation, and so on all industries connected with the soil. The range of temperature, or more exactly the temperature of winter, has some effect on transportation, especially by means of water. Navigation ceases, for example, on the Great Lakes, because ice forms about their borders in winter.

Temperature and Movement

When air is heated it expands and becomes lighter. This results in movements of convection (Fig. 358). One of the movements involved in convection is horizontal, as already pointed out, and horizontal movement of the air is wind. *Unequal heating of the air is, therefore, a cause of air movements,* and since the air is being unequally heated all the time, it follows that unequal heating is a constant cause of atmospheric movement. Some of the movements are horizontal, and some vertical; some are in the lower part of the air, and some in the upper.

The unequal heating of the air is the immediate cause of certain familiar winds and breezes.

1. *Land and sea breezes.* In a sunny summer day the land becomes warmer than an adjacent lake or sea (p. 340). The result is that the air over the land is warmed and expanded more than that over the sea. Movement of the air follows. By day, especially after some hours of heating, the air moves in from the water to the land at the bottom of the atmosphere. This is the *sea-breeze* or *lake-breeze.* At night the land cools more than the water, and the movements of air are reversed, giving the *land-breeze,* which blows from the land to the water at the bottom of the atmosphere. The causes of these movements will be more fully explained in Chapter XV.

The sea-breeze is strongest during the summer in warm regions. When the sea or land breeze has the same direction as the prevailing wind, it occasionally, as at Valparaiso (Chile), is so strong that business is stopped and people forced to seek shelter. Along certain coasts fishermen put to sea in the early morning with the land-breeze, and return at night with the sea-breeze.

2. *Monsoons.* Some lands near the sea become so much heated in summer that the sea (from-sea) wind continues during the hot season, not merely through the hot part of the day, while the land (from-land) wind holds sway during the winter. This is the case, for example, in India. Such winds, which change their directions with the seasons, are *monsoon winds.* The monsoon winds of the Indian Ocean had great influence on the early trade of India. Vessels sailing from Europe used to time their outward voyages so as to take advantage of the southwest monsoon, and their return voyages so as to take advantage of the northeast monsoon.

3. *Mountain and valley breezes.* Winds due to changes of temperature sometimes blow about mountains. *Mountain-breezes* blow from the mountains at night, and *valley-breezes* blow toward them on sunny days.

Mountain and valley and land and sea breezes, and monsoon winds are not the only ones due to differences of atmospheric temperature, but they afford the simplest illustrations of air movements due to this cause.

Vertical movements and temperature. It has been stated already (1) that when air rises it expands, and that as it expands it becomes cooler; and (2) that when air descends it becomes denser and warmer. These changes of temperature have an important influence on rain, snow, etc., and will be considered in connection with those topics.

CHAPTER XIV

THE MOISTURE OF THE AIR

The atmosphere always contains water in the form of vapor. This is true even in the desert, where the air seems driest. We cannot see or smell or feel water vapor, though air with much water vapor has a different feeling from air with little.

The presence of moisture in the air may be proved in various ways. If a pitcher of ice-water stands in a warm room, drops of water often appear on the outside of it. This water came from the air. Water vapor sometimes condenses into water in the air, and the water then becomes visible as clouds from which rain may fall.

Water vapor is lighter than dry air. That is, a cubic foot of it weighs much less than a cubic foot of dry air at the same temperature and under the same pressure. The water vapor of the air displaces some of the oxygen and nitrogen, and its presence therefore makes the air lighter.

Function of atmospheric moisture. The moisture of the atmosphere is of great importance to all animals and plants, for without it no life could exist. It furnishes the rain and the snow which supply all springs and rivers, and it serves a most important function in connection with temperature, as already indicated, for it absorbs heat radiated from the sun and from the earth. It increases the average temperature at the bottom of the atmosphere, and reduces the extremes of heat and cold which would exist if the air were altogether dry.

Sources of water vapor: evaporation. Water left standing in an open dish presently disappears, and any fluid, such as ink, which contains much water dries up if left uncovered. Muddy roads and wet streets soon become dry when the rain ceases. We conclude, therefore, that *the water vapor is passing constantly from* *all moist surfaces into the air.* The change of liquid water into water vapor is *evaporation.*

The surfaces of oceans, lakes, ponds, and rivers are always giving water vapor to the air. Evaporation takes place from land surfaces also, even when they seem dry. The rock beneath the surface contains water, and moisture is continually passing up from it into the atmosphere. Evaporation also takes place from snow and ice, even though the temperature is far below that of melting. This is shown by the fact that snow and ice slowly disappear even when the temperature is below 32° F. A wet cloth put into a very low temperature, say 0° F., freezes stiff; but if it stays at the same temperature long enough, it becomes dry. The ice in it has evaporated.

All animals breathe out water vapor into the atmosphere. This is seen in winter, when the water vapor of the breath condenses, and so becomes visible, in the cold atmosphere. The water breathed out is not seen in summer, or in a warm room, because it does not condense in warm air. Plants also breath out moisture, the amount being very great. In some cases it has been actually measured.[1] Thus a thrifty sunflower plant, during its life of 140 days, was found to give off 145 pounds of water. Grass was found to give off its own weight of water every 24 hours, in hot weather. This would mean 6½ tons per acre, and a little more than one ton for a lot 50 feet by 150 feet. A birch-tree, with 200,000 leaves, was estimated to give off 700 to 900 pounds on a hot summer day, though very much less, perhaps not more than 18 to 20 pounds, on cool days. Much water vapor also escapes from active volcanoes (p. 256).

The oceans must be looked upon as the great reservoirs from which most water comes, and but for them the waters of the land would all be dried up in the course of time. It is true that the ocean receives water from rivers, springs, and rains about as fast as it loses it by evaporation; but the water which falls as rain is largely from the ocean, and if the ocean stopped yielding the water vapor which furnishes the water for the rain, all the waters of the land would dry up.

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[1] Bergen, Foundations of Botany, p. 164.

Water is therefore in constant circulation in the air. The circuit which it makes is somewhat as follows: It is (1) evaporated from the ocean, then (2) diffused or blown over the land, where some of it (3) falls as rain or snow, feeding rivers, springs, lakes, etc. (4) A part of this water which falls from the air returns to the sea, while another part is evaporated into the air again without flowing to the sea. The evaporation of water and the circulation of the water vapor in the air are therefore important, not only for us, but for all living things.

On the average, 30 to 40 inches of rain-water fall from the air each year on land; that is, enough to make a layer 30 to 40 inches deep if spread out over all the land. The amount of water evaporated each year must be about the same as the amount which is precipitated. If the precipitation (rainfall and snowfall) on the oceans is equal to that on the lands, and if all were taken from the oceans *and not returned*, the oceans would be dried up in 3,000 or 4,000 years. If an amount of water equal to all the rainfall were evaporated from the lakes of the earth, it would probably dry them up in less than a year.

Rate of evaporation. Fig. 365 shows the amount of evaporation, in inches of water, which there would be from surfaces of water in various parts of the United States, if bodies of water such as lakes were present. Thus in Mississippi a surface of water would be lowered more than 50 inches in a year by evaporation; at New York, about 40 inches; at Milwaukee, about 30 inches; at Lake Superior, about 20 inches; at Denver, about 70 inches; and in southern Arizona, 90 to 100 inches. Since there are not lakes in all these regions, the diagram really shows only the *relative rates of evaporation from water surfaces* in the different regions.

Several conditions affect the rate of evaporation. The principal ones are (1) the amount of water vapor already in the atmosphere, (2) the temperature of the water and of the space over it, and (3) the strength of the wind. Fig. 365 shows the greatest evaporation in the driest part of the country, viz., Arizona and southern California. It also shows that evaporation is greater in the warmer latitudes of the United States than it is in the cooler latitudes. Water evaporates more rapidly in the wind than in still air. The

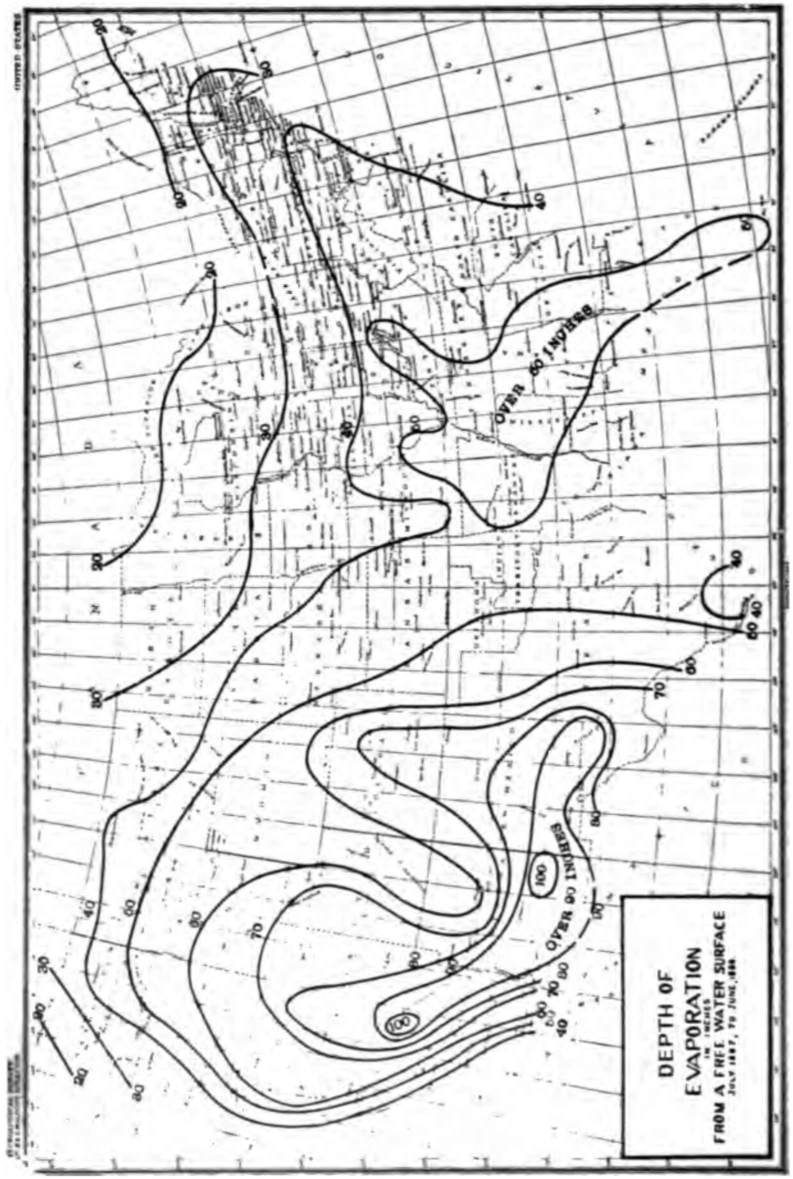

Fig. 365. Map showing the depth of evaporation, in inches, in the United States. The numbers on the lines show, in inches, the amount of water which would be evaporated each year *if water were freely exposed*. (Chart based on computations, not actual measurements. (T. Russell, Monthly Weather Review, December, 1904.)

reason appears to be as follows: When the air is still, the space just above a body of water or a moist surface receives much water vapor. This vapor in the air tends to retard evaporation; but when the air is moving, the water vapor in the air is carried away about as fast as it is formed, so that new and often drier air comes in over the surface from which evaporation is taking place.

The air influences evaporation (1) by its movement, as just noted, and also (2) because it affects the temperature above the land and water (p. 352); but evaporation would go on in a vacuum at a given temperature, even more rapidly than in air at the same temperature.

Evaporation takes up heat. Evaporation cools the surface from which it takes place. If the hand be moistened, it feels cool as the water on it evaporates, and the faster the evaporation the more distinct the cooling. Moist clothing seems cooler in the wind than in still air, even when the temperature is the same, because wind hastens evaporation. It takes about 1,000 times as much heat to evaporate a pound of water as it would take to raise its temperature 1° F. The evaporation from forested regions in moist tropical lands is so great that the temperature there is often much lower than would be expected from the insolation. The absence of evaporation in dry regions is one reason why they are so hot in the sunny days of summer.

Heat is a form of energy, and since heat seems to disappear in evaporation, energy has been used. Assuming the average amount of rainfall to be 60 inches, Strachey estimated that the energy necessary to evaporate it and lift it 3,000 feet (the average height from which rain falls) would be equal to 300,000 million horsepower constantly in operation.

Amount of water vapor in the air. The amount of water vapor in the air varies greatly from place to place, and from time to time at the same place. Attempts have been made to estimate the amount in the air at one time, but the results are far apart. It is probably enough so that if it all fell as rain at once it would make a layer of water at least an inch thick.

Some idea of the amount of water vapor in the air is gained in another way. One cubic foot of space at 0° F. is capable of containing ½ grain of water vapor; at 60° F., 5 grains; and at 80° F., 11 grains. The weight of air in a room 40 x 40 x 15 feet, at a temperature of 60° F., and under ordinary pressure, is about 1,800 pounds. The weight of water vapor which this space is capable of containing is nearly 20 pounds.

The amount of water vapor in the air at any place at any time depends on the temperature, and on the available supply of water. The higher the temperature, the more the water vapor which a given space can hold. About ¾ of all the water vapor in the air is in the lowermost two and one-half miles of the air, and about 24/25 in the lowermost five miles.

Atmospheric moisture and atmospheric movements. Since water vapor makes the air lighter, and since movements result when the air of one place is lighter than that of another, it follows that differences in the amount of moisture in the air in different places are a cause of atmospheric movements.

Saturation. When the air has all the water vapor which it can hold, the air is said to be *saturated*. Though it is customary to speak of the *air* as being saturated, yet it is, in reality, not the air which is saturated, but the *space* which the air occupies. The amount of water vapor necessary to saturate a given space depends on the temperature, and is nearly the same whether air is present or not.

Humidity. The amount of moisture which the air contains is its *absolute humidity*. The percentage of moisture which air contains at any temperature, in comparison with what it might contain at that temperature, is known as its *relative humidity*. When it contains all the water vapor it can hold, its relative humidity is 100; when it contains half as much as it might, it has a relative humidity of 50. Air is commonly said to be "dry" when its relative humidity is low, and "moist" when its relative humidity is high. Fig. 366 shows the average relative humidity for the United States, the range being from 80 along the coasts to less than 40 in some parts of the southwest. The area where the relative humidity is 35 or less is essentially desert, and the area where it is less than 50 is distinctly dry. In Death Valley, California, the average relative humidity for five months when the record was kept was

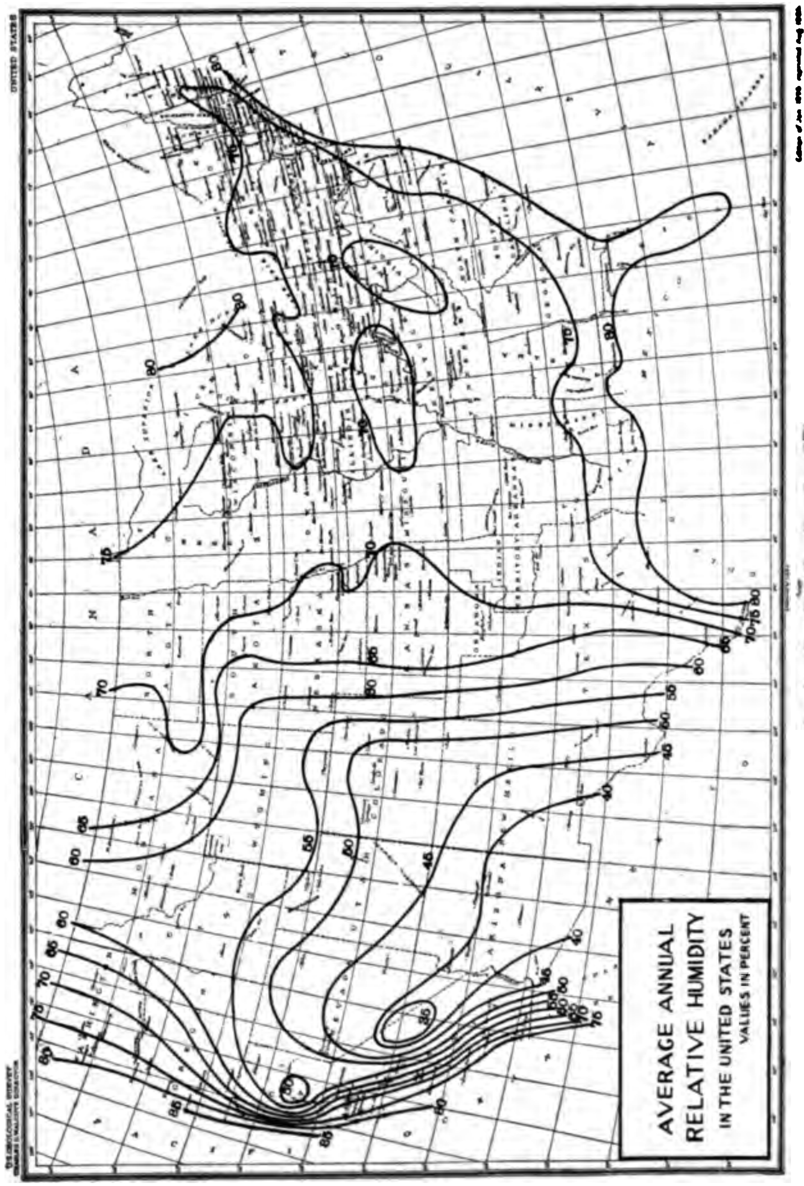

Fig. 366.—Chart showing the average annual humidity of the atmosphere in the United States. (Cox, U. S. Weather Bureau.)

23. In the heat of the day during the summer, the relative humidity occasionally falls as low as 3. This extremely low humidity has been recorded at Tucson, Arizona. A humidity so low as this is, however, extremely rare, and lasts for but a few hours.

The average relative humidity of air over the land is probably about 60; that over the ocean about 85. The part of our country which is productive, agriculturally, without irrigation, is chiefly where the relative humidity is more than 65.

Dew-point. If saturated air is cooled, some of its moisture is *condensed*. The temperature at which the water vapor of the air begins to condense is the *dew-point*. Saturated air is therefore at the dew-point. This point is not a fixed temperature, but is influenced by the amount of water vapor in the air. When this amount is large, the temperature of the dew-point is relatively high; when the amount is small, the temperature of the dew-point is relatively low.

Air may be brought to the dew-point in various ways: (1) It may be blown where the temperature is lower, as up to a higher latitude or altitude; (2) it may be cooled by having cooler air brought to it, as by a cold wind; (3) it may be cooled by radiation, or (4) by expansion, as when it rises (p. 347).

Condensation. When the temperature of saturated air is reduced, some of the water vapor is condensed. If the temperature of condensation is above 32°, the vapor condenses into liquid water, which at first takes the form of little droplets, such as those of which fog is made. If the temperature of condensation is less than 32°, the water becomes solid (crystallizes) as it condenses, and takes the form of ice particles. These ice particles may be the beginnings of snowflakes, or they may be particles of frost.

Condensation of water vapor sets heat free. When the water vapor of the air is condensed, an amount of heat equal to that absorbed in its evaporation is set free. This is why rising moist air is not cooled so rapidly as rising dry air (p. 347). Dry air is cooled about 1° F. for every 183 feet of rise, but saturated air at 68° F. must rise nearly twice as much to be cooled 1° F., because of the heat set free by the condensation of moisture during the rise.

Fog, frost, and cloud. The water droplets made by the condensation of water vapor make *fog* (Fig. 367) if the condensation takes place in the lower part of the atmosphere at a temperature of more than 32° F., and the form of frost if the temperature is less than 32° F. The water droplets and ice particles take the form of *clouds* if the condensation takes place above the bottom of the atmosphere (Fig. 370). Fog and frost in the air are the same as clouds, except that the clouds are higher. Fog is cloud resting on the surface of the land. If moisture condenses and the particles remain suspended in the air above the top of a mountain, there is, to the observer on the plain or in the valley below, a cloud about the mountain; but if the observer were to climb up into the cloud, it would then appear to be fog. Fogs are often formed when the air over a lake in autumn is blown over the cooler land, or when the air over warmer water from one part of the ocean (e. g., a warm ocean current) blows over colder water.

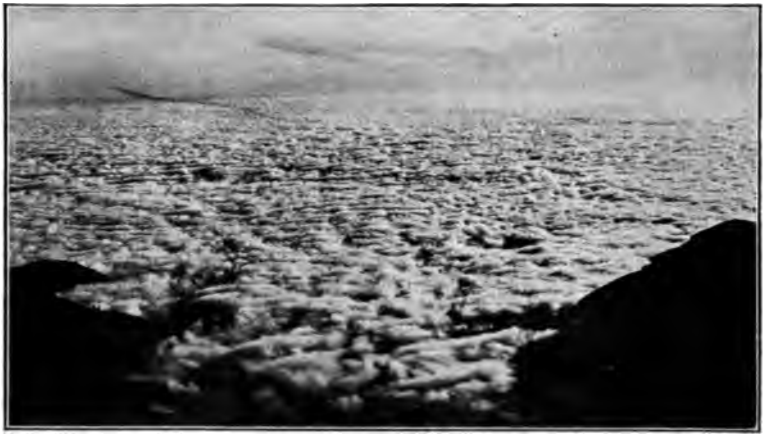

Fig. 367.—Fog over the lowlands, seen from Mount Wilson, California. Los Angeles and Pasadena are covered by the fog. (Ellerman)

Fogs often form in valleys at night (Fig. 368), especially in autumn, when the night temperatures are much lower than those of the day. The cooler air settles in the valleys, which are therefore more likely to have fogs than the uplands are.

Fogs occasionally lead to shipwreck on sea, and interrupt business on land. A dense fog in London, which lasted from December 10 to 17, 1905, was estimated to have cost the city $1,750,000 per day, in one way and another, largely through suspension of

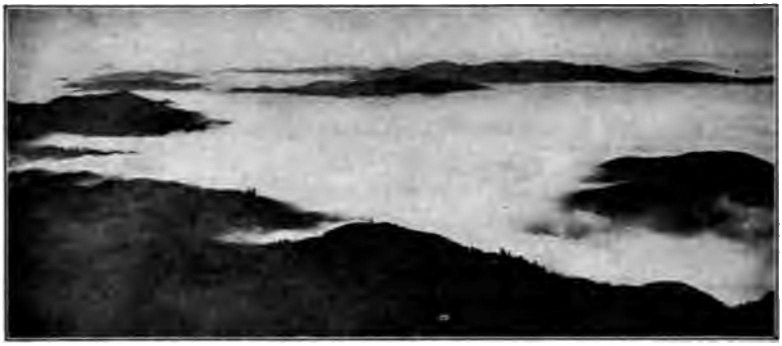

Fig. 368.—Morning fog over valleys. Mount Tamalpais, California. (U. S. Weather Bureau.)

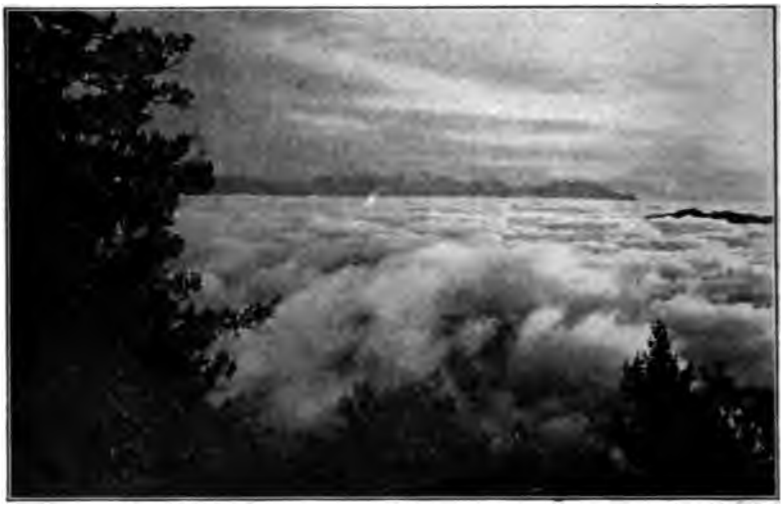

Fig. 369. From Mount Wilson, California. The clouds or fog cover all the lowland. (Ellerman.)

business. Such estimates are, however, to be taken with reserve, since much of the suspended business is transacted later. Heavy fogs may be of service to one party in war, by allowing an army to approach or retreat unseen. Thus a fog helped Washington in his retreat to New York, after the battle of Long Island.

The droplets of water in clouds and fogs must be very small to remain suspended in the air. It has been estimated that they are often about $\frac{1}{3000}$ of an inch in diameter, but there is doubtless great variation.

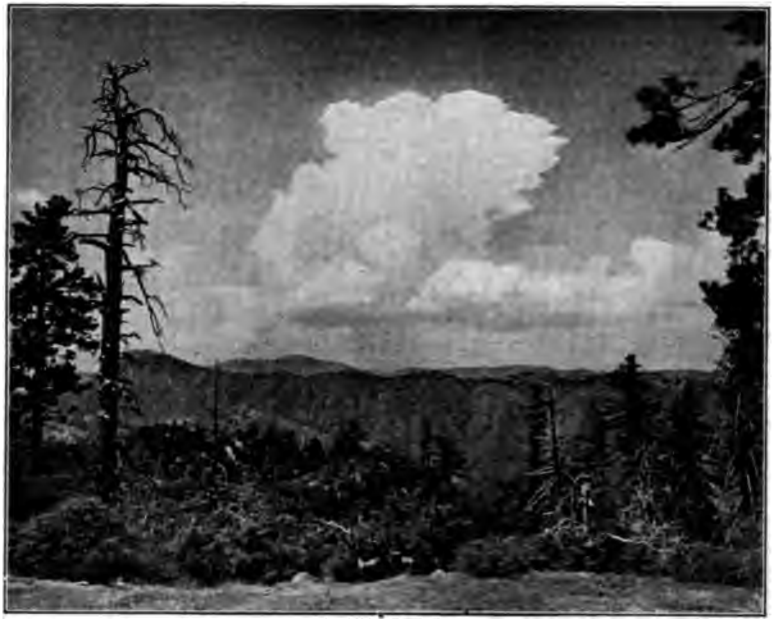

Fig. 370.—Cumulus clouds seen from Mount Wilson, California. (Ellerman.)

Clouds affect temperature by hindering radiation. A cloudy night is not generally so cold as a clear one. In general, cloudiness lowers the summer temperatures of middle latitudes and raises their winter temperatures.

Forms of clouds. Clouds take on many forms. Among the more common are the *cumulus*, the *stratus*, the *nimbus*, and the *cirrus* clouds. Between these more distinct forms there are many gradations, giving rise to the names cirro-cumulus, cirro-stratus, cumulo-stratus, etc.

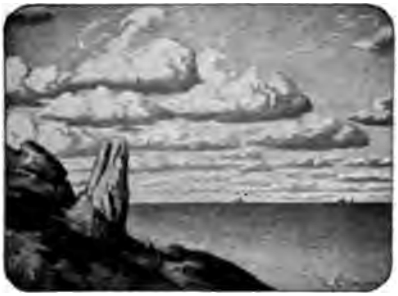

Fig. 371.

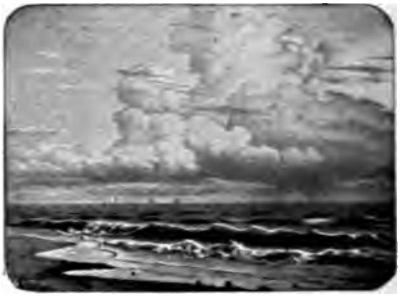

Fig. 372.

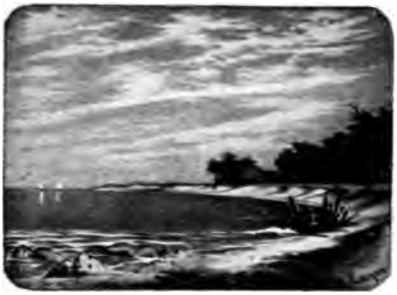

Fig. 373.

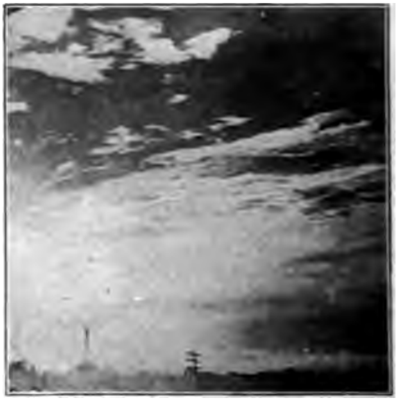

Fig. 374.

Fig. 371.—Cumulus (wool-pack) clouds. (From Cloud Chart, Hydrographic Office, Dept. of the Navy.)
Fig. 372.—Cumulo-nimbus clouds. (From Cloud Chart, Hydrographic Office, Dept. of the Navy.)
Fig. 373.—Cirrus clouds. (From Cloud Chart, Hydrographic Office, Dept. of the Navy.)
Fig. 374.—Cirro-stratus clouds. (U. S. Weather Bureau.)

Cumulus clouds are thick, and their upper surfaces are somewhat dome-shaped, with irregular and fleecy projections. Their bases are nearly horizontal (Figs. 370 and 371). They are formed by ascending convection currents, and their level bottoms seem to mark the level at which condensation takes place as the air rises. They appear, especially in clear, hot weather, in mid or late forenoon, after insolation has established convection currents. They grow as the heat of the day increases, and attain their greatest size at about the hour of maximum heat. As evening approaches they commonly grow smaller. They sometimes pass into other forms of cloud.

Stratus clouds are horizontal sheets of lifted fog.

Nimbus or *rain clouds* (Fig. 372) consist of thick layers of dark clouds without definite shape and with ragged edges, from which continued rain or snow generally falls.

Cirrus clouds are delicate, fibrous, or feathery (Figs. 373 and 374). They are generally white, and sometimes arranged in belts. They are usually high and thin, and often of particles of snow or ice.

Between these types there are all sorts of gradations.

Precipitation. The condensation of the water vapor of the air leads to rain, snow, or hail, if the products of condensation fall. Whether precipitation really takes place after the formation of clouds depends on many conditions. To give rain or snow, the particles of water or snow in the cloud must be heavy enough to fall; and if they are to reach the bottom of the atmosphere, they must not pass through air which is dry enough and warm enough to evaporate them before they reach the bottom of the atmosphere. In desert regions water may sometimes be seen to be falling from a high cloud, when not a drop reaches the ground. The falling drops evaporate before they reach the land. This has been seen, for example, about San Francisco Mountain, Arizona.

Whether precipitation takes the form of rain or snow depends on the temperature of condensation, and on the temperature of the air where the precipitation takes place. Snow falling from a cloud may become water before it reaches the bottom of the air; it often *snows* on a mountain while it *rains* in the valley below

Since condensation follows cooling, and since precipitation often follows condensation, sufficient cooling (below dew-point) of the air may cause precipitation. It follows that there may be rain (or snow) (1) when air is blown up a cold mountain-side; (2) when it is blown poleward (or, in general, from a warmer to a cooler place) without rising; (3) when it rises by convection, for it is then cooled both (*a*) by being brought to cooler air, and (*b*) because it expands; and (4) when cooler air is brought to warmer air. Rains due to (1) are not rare in mountain regions, and rains due to (3) are common where convection currents are strong, as in the region of tropical calms, where they occur almost daily during the hottest part of the day.

The *distribution* of rainfall is dependent, in large measure, on the winds, and will be considered later.

Dew and frost. It sometimes happens that the temperature of the surface of the land becomes lower than the dew-point of the air. This is likely to be the case in the clear nights of late summer and autumn. If the temperature of the grass blades, for example, becomes lower than the dew-point of the surrounding air, moisture from the surrounding air will be condensed on them. Such moisture is *dew*. Dew does not fall, but condenses on the surface of solid objects. A good illustration of dew is often furnished by the moisture which gathers on the outside of a pitcher of ice-water in a summer day. The temperature of the pitcher is below the dew-point of its surroundings, and moisture from the air therefore condenses on it. Dew forms on still nights rather than windy ones, because the wind tends to move away the air which is approaching its dew-point, supplying other air in its place, and the incoming air is often warmer than that which moved on. Dew is more likely to form on clear nights than on cloudy ones, because radiation and cooling are greater when there are no clouds.

When the temperature of the dew-point is below 32° F., the moisture which condenses on solid objects condenses as frost instead of dew. Frost is not frozen dew any more than snow is frozen rain. It stands in the same relation to dew that snow does to rain. In the autumn, frost is more likely to occur in valleys and on low flats than on adjacent hills, because the colder air settles to the lower levels.

Dew, and sometimes frost, may form on the undersides of objects. If a pan is placed bottom up on the ground, there will often be dew on the inside of it in the morning. There is often dew on the underside of a flat stone when there is none on its top. This may be true even in a desert. The explanation is as follows: The air in the ground has some moisture, and during the day, when the sun shines, this air is warmed. At night the air above cools much more quickly than the air in the ground. The cooler, heavier air above then sinks into the ground, crowding up the warmer air below with its water vapor. On reaching the cool pan, or other object, some of the moisture is condensed. In the daytime the rising moisture would not condense on the pan, because the pan would be warmer than the water vapor below, if the sun were shining. The water vapor in the soil also diffuses upward, even when not crowded up by the sinking of heavier air.

Rain-making. Various attempts have been made to produce rain, by means which may be called artificial. The methods tried have been various, but the results have been unsuccessful always. The plan most tried has been that of producing explosions of one sort or another in the air well above the land. If there were cloud particles in abundance in the air, such disturbances might perhaps have the effect of causing them to unite, and so to become large enough to fall; but the amount of rainfall which can be thus produced, under the most favorable conditions, is probably too small to be of consequence. Other methods which have been tried or suggested seem equally useless.

Summary. The air is constantly taking up moisture from all moist surfaces. This moisture, in the form of invisible vapor, is diffused and blown everywhere. When it reaches a temperature which is low enough (the dew-point), the moisture is condensed. If it condenses in the upper air, it may fall as rain or snow, or it may remain suspended in the air in the form of a cloud, and be evaporated again. If it condenses on the surface of solid objects at the bottom of the atmosphere, it forms dew or frost. Water vapor is thus in constant circulation, and all land life depends upon it. Some of the water which is precipitated out of the atmosphere falls on the surface from which it was evaporated, but much of it falls in places far distant from those whence it was evaporated.

CHAPTER XV

ATMOSPHERIC PRESSURE

The familiar facts already cited (p. 323) show that the air has weight. Its downward pressure (or weight) has already been stated to be, on the average, nearly 15 pounds to the square inch at sea-level. But it is not the same at all places at the same level, and differences in pressure at the same level are the primary cause of movements of the air. These movements are *winds*. It is convenient to have some simple method of measuring and recording atmospheric pressures. The instrument by which the pressure of the atmosphere is measured is the *barometer*.

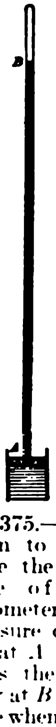

Fig. 375.— Diagram to illustrate the principle of the barometer. The pressure of the air at *A* maintains the mercury at *B* in the tube when there is no air in the tube above *B*.

The barometer. The principle of the barometer is as follows: A tube more than 30 inches long, closed at one end, is filled with mercury. The open end of the tube is then placed in a dish of mercury (Fig. 375). The mercury in the tube will sink until its upper surface reaches a level about 30 inches above the level of the mercury in the dish, if the place of the experiment is near sea-level. The mercury remains at this level in the tube because the pressure of the air on the mercury in the dish is enough to balance the downward pressure or weight of the mercury in the tube. Since the pressure of the air at sea-level holds the mercury in the tube up about 30 inches (or 760 millimeters), the pressure of the air at sea-level is said to be 30 inches (or 760 millimeters). If the atmospheric pressure becomes less, the mercury in the tube falls, and if the atmospheric pressure becomes greater, the mercury in the tube rises.

At elevations above sea-level the pressure is less, and the higher the rise the less the pressure, as shown in the following table:

Altitude above sea-level, in feet.	Barometric pressure in inches.
0	30
1,800	28
3,800	26
5,900	24
8,200	22
10,600	20
13,200	18
16,000	16

The decrease of pressure with increasing height being known, the altitude above sea-level may be measured by means of the barometer; but since mercurial barometers are not convenient to carry and are easily broken, another form of barometer, the *aneroid* barometer, has been devised for this purpose.

Air pressures unequal. The pressure of the atmosphere varies from point to point, and from time to time at the same point. Some of the reasons are as follows:

1. The temperature of the surface on which the air rests is unequal, and increase of temperature makes the air lighter. As the temperature varies, the pressure varies.

2. A cubic foot of dry air at a temperature of 68° weighs 523.72 grains under a pressure of 30 inches. A cubic foot of saturated air under the same conditions weighs 4.26 grains less (p. 364). Water vapor makes the air lighter because it crowds out some of the oxygen, nitrogen, etc., which weigh more than the water vapor which displaces them. On the whole, the amount of moisture in the air is greater in warm regions (but not in hot deserts) than in cold ones, and greater over moist surfaces than over dry ones. Since the amount of moisture in the air varies from time to time, the pressure is constantly changing.

If temperature and moisture were the only factors controlling air pressure, the pressure would be least in low latitudes where it is warmest, and where there is abundant moisture.

The distribution of atmospheric pressure does not agree with these general rules. We conclude, therefore, that temperature and moisture are not the only things which affect atmospheric pressure.

Representation of Pressure on Maps and Charts

Isobars. Lines may be drawn on the surface of the earth connecting points where the atmospheric pressure is equal. Such lines are *isobars.* A map showing lines of equal pressure is known as an *isobaric map* or *chart.* An isobaric chart for the year, that is, an annual isobaric chart, shows isobars connecting points having the same *average pressure* throughout the year. There may be isobaric charts for a season, for a month, or for any shorter period. The daily weather maps are daily isobaric charts. Fig. 376 represents an isobaric chart for the year. The figures on the lines indicate the average pressure for the year in inches.

In the southern hemisphere, the isobar of 30 inches encloses a belt extending almost around the earth, being interrupted only in the vicinity of Australia. Every point within the area enclosed by this isobar has an average atmospheric pressure of more than 30 inches. Every point within the isobar of 30.10 inches has an average annual pressure of more than 30.10 inches, while every point between the isobars of 30 and 30.10 has an average annual pressure of more than 30 and less than 30.10 inches, etc. Between the two adjacent isobars of 29.90 in the equatorial part of the Atlantic, the pressure is less than 29.90, but not so low as 29.80. If the pressure sank to the latter figure, there would have been isobars of 29.80 inches.

It will be remembered that the temperatures shown on an isothermal chart are not those actually observed, but that allowance is made for altitude above sea-level. In the same way, the pressures shown on an isobaric chart are not those actually observed on the land. *They are the pressures which would exist if there were no elevation above sea-level.* The allowance which must be made for elevation above sea-level varies with the temperature and the pressure. When the temperature is 70° F. and the pressure 30 inches, 95 feet of elevation diminishes the pressure 0.1 of

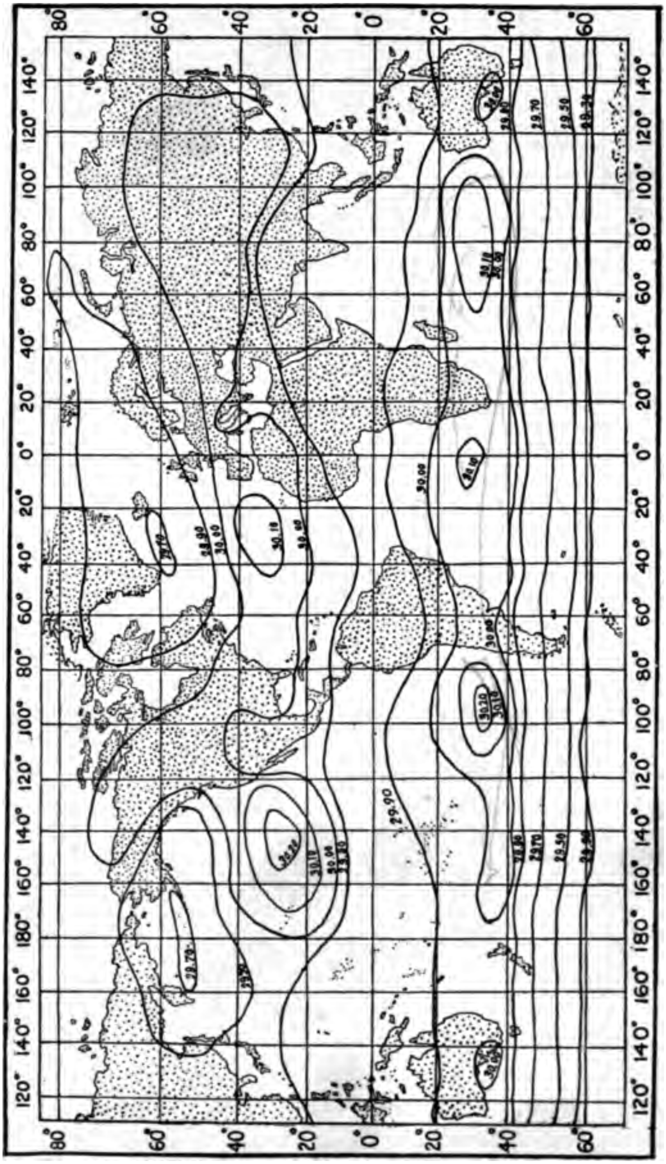

Fig. 376.—Chart of annual isobars. (After Buchan.)

an inch. If the pressure 95 feet above sea-level is 30 inches, it would be put down on the isobaric chart 30.1. If the temperature were lower, 0.1 of an inch would be added for a lesser height, since colder air is heavier.

Isobaric surfaces. An isothermal surface connects places having the same temperature. So an *isobaric surface* connects places having the same pressure, that is, the same weight of air above.

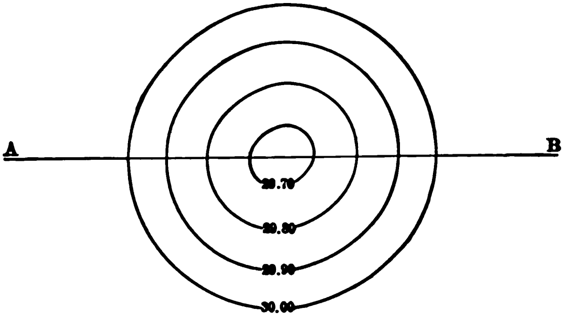

Fig. 377.—A series of isobaric lines showing diminishing pressure toward the center.

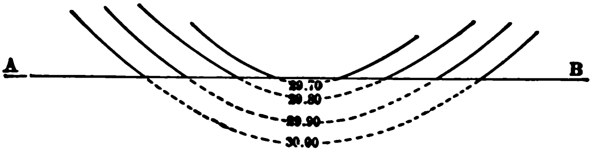

Fig. 378.—Section through the area represented in Fig. 377, showing the position of isobaric surfaces. As the pressure toward the center of the area shown in Fig. 377 diminishes, the isobaric surface bends downward. It will be seen that *isobaric lines are the lines where isobaric surfaces cut sea-level.*

If, for example, one place at sea-level had a pressure of 30 inches, and another a pressure of 30.10 inches, the isobaric surface of 30 inches would lie above sea-level at the place where the pressure was 30.10 at sea-level. If the pressure at sea-level at another place were 29.90 inches, the isobaric surface of 30 inches would be below sea-level there. An isobaric surface, therefore, has slopes. Fig. 377 shows a series of isobars, with the pressure least at the center, and Fig. 378 shows the slope of the isobaric surfaces in the same place. Fig. 379 shows another series of isobaric lines, with the pressure greatest at the center, and Fig. 380 shows the slope of

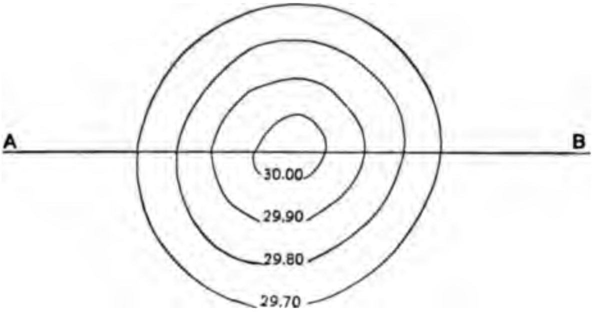

Fig. 379.—A series of isobaric lines showing increasing pressure toward the center.

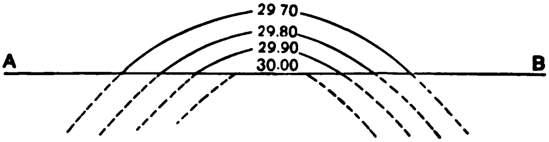

Fig. 380.—Section through the area represented in Fig. 379, showing the position of the isobaric surfaces. As the pressure toward the center of the area shown in Fig. 379 increases, the isobaric surface bends upward.

isobaric surfaces in the same region. Fig. 381 shows the general direction of isobaric slopes in longitude 40° W., corresponding with Fig. 376. The slopes are away from the places of high pressure and toward places of low pressure.

If a surface of water had the form shown by the uppermost line in Fig. 378, the water would flow in from all sides until the surface

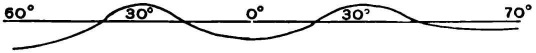

Fig. 381.—Diagram showing the general slope of isobaric surfaces in longitude 40°, based on the isobaric lines of Fig. 376.

became level. If the water surface had the form shown in Fig. 380 the water would flow away from the top in all directions. The air, which is more fluid than water, acts in a similar way, and *moves down the slope of an isobaric surface,* if it has slope. Such movements of air are winds. When the isobaric slope (or *isobaric gradient*) is high, the wind is strong; when the isobaric gradient is low, the wind is gentle; and when there is no isobaric gradient, that is, when the isobaric surface is level, there is no wind. The strong wind is strong for much the same reason that a swift river is swift; the gentle wind is gentle for much the same reason that the slow river is sluggish; while the absence of wind may be compared to the pond in which there is no perceptible current because there is no slope of the surface.

Isobaric charts show the direction and strength of winds, and winds are controlled by isobaric surfaces. In order to know what the winds of a given place will be, we must know the pressures of adjacent areas *at the same level.* For example, it is not the difference in pressure between the top of Pike's Peak (*A*, Fig. 382) and Denver (*D*, Fig. 382), as measured at the two places by a barometer, which determines the winds between these places; but it is the pressure at the top of Pike's Peak, as compared with the pressure *at the same elevation* over Denver (*B*, Fig. 382), which is significant. If the isobaric surface at *A*, extends as a plane to *B*, there will be no wind between the two places, because the isobaric surface has no slope. To know what the winds are to be, therefore, we must compare pressures at the same level, and this is why all isobars are reduced to sea-level.

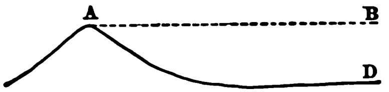

Fig. 382.—It is the atmospheric pressure *at the same level in adjacent areas* which determines movements of air.

Returning now to Fig. 376, several points are readily seen: (1) The isobars have a general east-west course, though many of them are not straight; (2) on the average, they show greater pressure in low latitudes than in high latitudes; (3) they are highest (that is, they show highest pressure) in the latitudes just outside the tropics; (4) they are more regular in the southern hemisphere than in the northern; and (5) they are, on the whole, more regular on the sea than on the land.

Isobars and parallels. It will be remembered that isotherms have a general east-west course. Is it the latitude, or the temperature which is largely determined by latitude, which influences the pressure, and therefore determines the course of the isobars?

Low latitudes have higher temperatures than high latitudes, and increase of temperature makes the air lighter. If temperature controls the position of isobars, they should be lowest at the equator and highest at the poles. Fig. 376 shows that this is not the case, and it shows that pressures are distributed in apparent defiance of temperature. The isobars are highest neither where it is coldest nor where it is warmest; they are highest neither in the lowest nor the highest latitudes. It is clear, therefore, that *neither latitude nor temperature, nor both together, control the position of isobars.*

We must not conclude, however, that temperature has no effect on isobars because it does not control their position. Increase of temperature expands air, and must make it lighter, and so decrease its pressure. We can only conclude that *latitude and temperature are not the chief factors which determine the distribution of atmospheric pressure,* and therefore of isobars. Something else must be of greater importance.

Relation of isobars to land and water. The isobars are much more regular in the southern hemisphere, where there is much water, than in the northern hemisphere, where there is less. This suggests that the distribution of land and water influences the position of isobars. It will be remembered that this was one of the factors influencing the position of isotherms. The land is warmer than the sea in the same latitude in summer, and cooler in winter; and anything which influences temperature should influence pressure also.

Seasonal isobaric charts. The isobaric map for January (Fig. 383) shows that the high-pressure (more than 30 inches) belt is very wide in the northern hemisphere (winter), especially on the land, which at this season is cooler than the sea. This supports the inference that high pressure goes with low temperature. In the southern hemisphere, January is a summer month, and the land is warmer than the sea. If high temperature causes low pressure, the pressure in the southern hemisphere at this time should be less than that in the northern, and it should be lower on the land than on the sea.

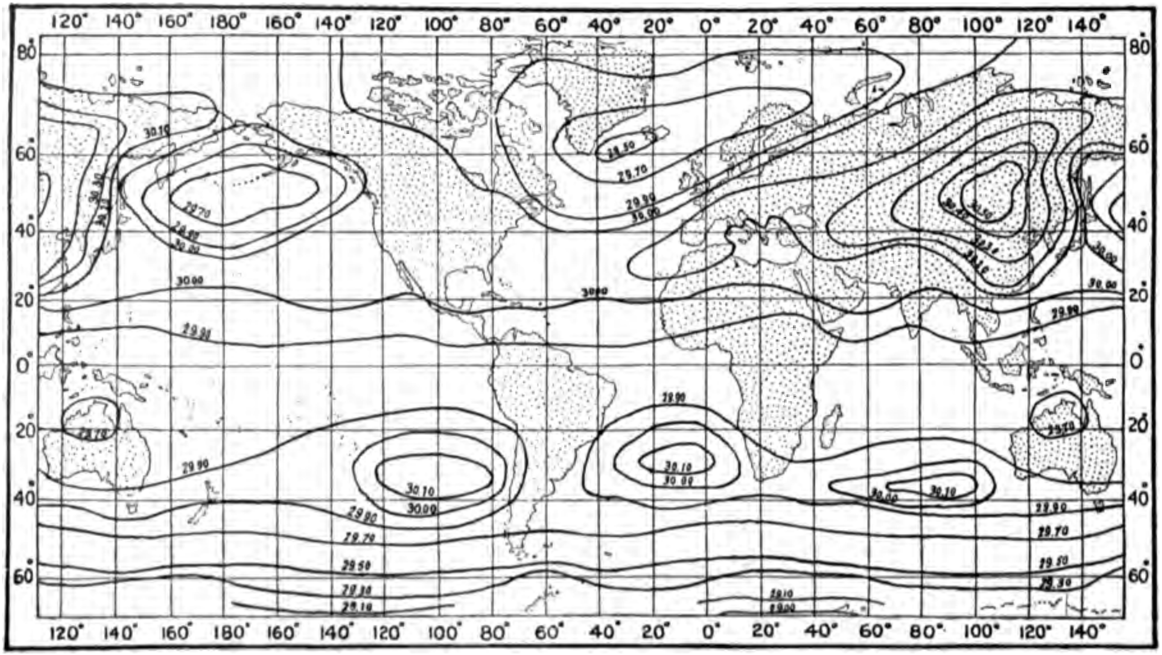

Fig. 383.—Chart of isobaric lines for January. (After Buchan.)

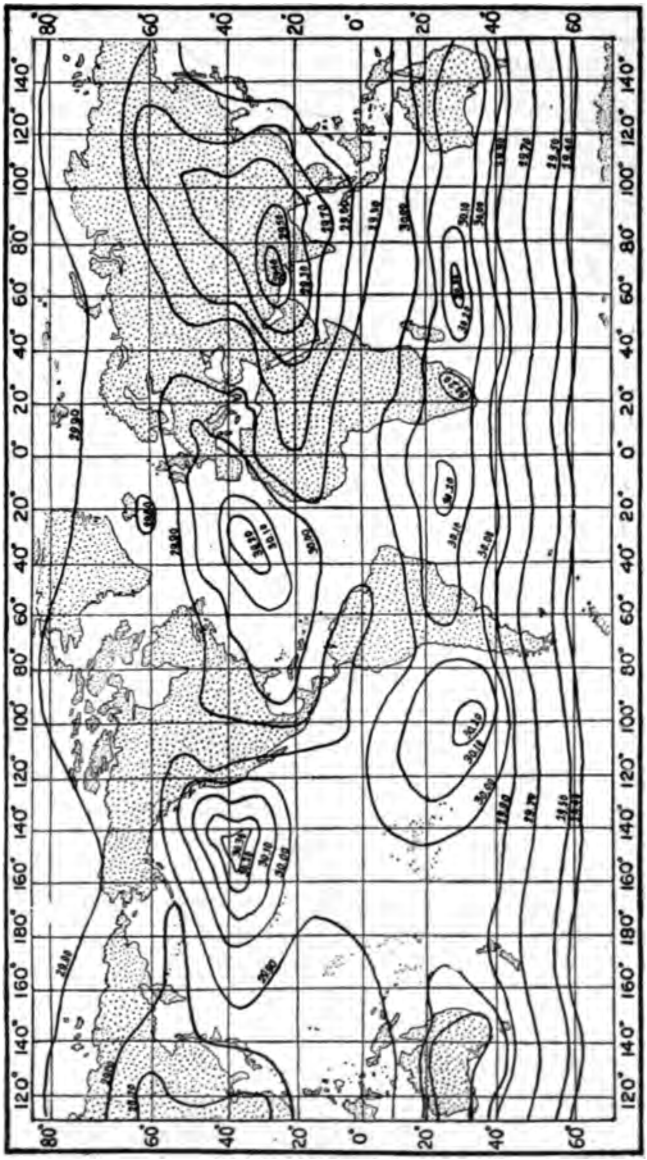

Fig. 384.—Chart of isobaric lines for July. (After Buchan.)

The map shows that both these things are true. This chart, therefore, seems to show that high temperature reduces pressure.

A study of the isobaric chart for July (Fig. 384) leads to the same conclusion. At that time of year, the pressure in the southern hemisphere (winter) should be higher, on the average, than in January (Fig. 383). Especially should it be higher on land, as the map shows it to be. In the northern hemisphere (summer), on the other hand, the pressure should be less than it was in January, and especially should it be less on land, which is much warmer than it it was in winter. Fig. 384 shows both these things to be true. We have confidence, therefore, in the conclusion that high temperature reduces the pressure, while low temperature increases it.

The charts furnish other evidences in support of the same conclusions. Some of them are the following:

1. Figs. 383 and 384 show that the atmospheric pressure changes from season to season in the same place. In January the pressure over the larger part of the United States exceeds 30 inches, while in July it falls short of 30 inches. The pressure in southern Africa exceeds 30 inches in July (winter), and falls short of it in January (summer). The pressure over much of Asia exceeds 30 inches in January, and falls short of it in July. Other illustrations of the same sort may be found on the maps. *In seasonal changes of temperature, increased temperature goes with decreased pressure.*

2. *The seasonal range of pressure, like the seasonal range of temperature, is greater on large land areas than on small ones.* It is nearly an inch in Asia; about .4 of an inch in North America and southern Africa; and still less in Europe and South America. This indicates the close relationship between isobars and isotherms.

3. Again, the seasonal variation of pressure, like the seasonal range of temperature, is less on the sea than on land.

Though a relationship between temperature and isobars is clear, it is also clear that the low pressures in high latitudes, and the high pressure in the tropical regions, features which appear on all the charts, *are not due to temperature.*

Isobars and humidity. We have seen (p. 375) that water vapor makes the air lighter. Are the isobars lowest over the oceans in warm latitudes, where the air contains on the average most moisture? The isobaric charts show that this is not the case. We conclude, therefore, that the amount of *moisture in the air is not the chief factor controlling the isobars*.

Inequalities of temperature and moisture in the air are the only factors thus far studied which might affect the isobars; and since they do not explain the most striking feature in the distribution of atmospheric pressure, namely the high pressures in low latitudes, we conclude that something besides temperature and moisture must be involved in their explanation.

The high-pressure belts. The explanation of the high pressure in low latiudes rather than in high, and the explanation of the highest pressures just outside the tropics, is not found on the isobaric charts. These larger features of pressure-distribution are to be explained by the general circulation of the atmosphere under the influence of rotation. The details of this explanation are here omitted.

Permanent areas of low pressure. Fig. 370 shows areas of low pressure in the North Pacific and North Atlantic oceans. These areas of low pressure are still more pronounced on the January chart (Fig. 383), and are feebly marked on the July chart (Fig. 384). No corresponding areas of low pressure are known in the southern hemisphere. The explanation of these areas of low pressure is not known.

Temporary and local variations of pressure. There are many variations of pressure not shown on seasonal or even on monthly isobaric charts, though they appear on daily weather maps. These will be studied in a later chapter.

CHAPTER XVI

GENERAL CIRCULATION OF THE ATMOSPHERE

Inequalities of atmospheric pressure produce *winds.* Since unequal heating, which produces unequal pressure, is going on all the time, inequalities of pressure are being renewed constantly. It follows that winds are always blowing. This results in *a general circulation of the atmosphere,* the movement being always from a region of greater pressure to one of less pressure, or in other words, *down an isobaric slope.*

Causes of Winds

The general effect of unequal insolation. If the air over the whole earth were quiet at a uniform, low temperature, and if it could then be heated by the sun for a time without any horizontal movement, the effect would be to raise its surface everywhere, and to raise it most where it was heated most, that is, in the low latitudes (Fig. 385), Under these conditions there would be a barometric slope from low latitudes toward high latitudes. ***Before horizontal movement began,*** there would be no change of pressure at the bottom of the air, for the same amount (mass) of air would lie over each place, as before the heating. But if the surface of

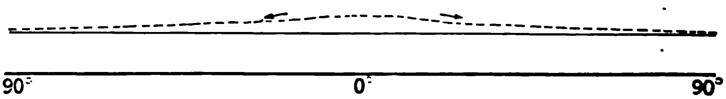

Fig. 385.—The lower line may be taken to represent the surface of the lithosphere, the upper full line, the upper surface of the atmosphere as it would be if the temperature were low, and everywhere equal. The dotted line at the top shows the effect of heating on the surface of the air. The heating raises the surfaces everywhere, but most in low latitudes. Movement would result as indicated by the arrows.

the air had the form shown by the dotted line in Fig. 385, the upper air would move as shown by the arrows. Since the air in low latitudes is always warmer than that in high latitudes[1], the upper air should always be moving from the equatorial zone to the polar zones in both hemispheres. These poleward movements of the upper air lessen the pressure at the bottom of the atmosphere in low latitudes, because air has moved away from that zone. *After air has moved from the equatorial region toward the poles* (Fig. 385) there is more air in the high latitudes than in the low. A barometric gradient is thus established *toward the equator at the bottom of the atmosphere* (Fig. 386). Air then moves from higher latitudes to lower latitudes at the bottom of the air.

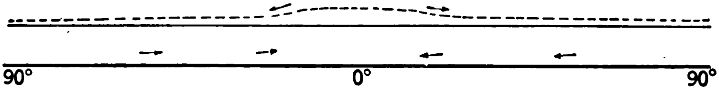

Fig. 386.—The movement of air indicated in Fig. 385 would result in the further movement shown by the lower arrows in this figure.

Here, then, we have the elements of a general circulation, a poleward movement in the upper air, and an equator-ward movement in the lower air, and the cause which generates these movments, unequal heating, is in operation all the time. This circulation includes both vertical and horizontal movements. So far as unequal heating is concerned, the *vertical movements* are upward in low latitudes, and downward in higher latitudes. The *horizontal movement* is poleward in the upper air in low latitudes, and there must be some return from the high latitudes, of the air which moves to them from the equatorial belt. The general circulation which would be

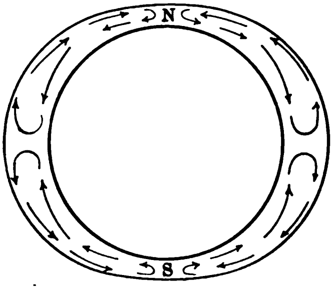

Fig. 387.—Diagram showing the general system of circulation which would be established by unequal insolation, as a result of differences in latitude.

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[1] High latitudes sometimes receive more heat per day than low latitudes (see p. 337), but the air of high latitudes is never so effectively heated, because of the abundance of ice, snow, ice-cold water, and frozen ground.

established by the greater heating of the low latitudes is somewhat as shown in Fig. 387.

If the earth did not rotate, the movements of air just outlined would tend to follow meridians. The poleward-moving air should blow north in the northern hemisphere, and south in the southern, while the air moving toward the equator would blow south in the northern hemisphere, and north in the southern hemisphere. Rotation turns the air currents to the right in the northern hemisphere, and to the left in the southern. Other things also interfere with the north and south directions of the winds, as we shall see.

Effect of the extra-tropical belts of high pressure. Leaving now the effect of unequal heating, let us note the effect of the high-pressure belts just outside the tropics (Fig. 376). From these belts the air flows to areas of lower pressure on either side, at the bottom of the atmosphere. If it were not for the rotation of the earth, the wind would blow north and south from each high-pressure belt. But the rotation of the earth causes the winds to turn to the right in the northern hemisphere, and to the left in the southern, as shown in Fig. 388, which represents the prevailing direction of the winds, at the bottom of the air, in low and middle latitudes. This figure shows distinct zones of winds.

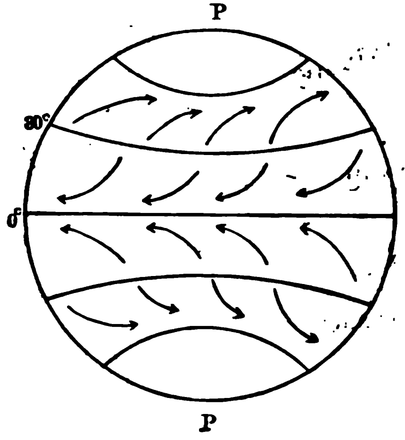

Fig. 388.—Generalized diagram of wind directions at the bottom of the atmosphere.

Wind zones. The poleward winds from the high-pressure belts are turned toward the east in both hemispheres, and so become *westerly winds* (southwesterly in the northern hemisphere, and northwesterly in the southern). The winds blowing from the belts of high pressure toward the equator become easterly (northeasterly in the northern hemisphere, and southeasterly in the southern), and are known as *trade-winds.* The zone along the thermal equator where the northeasterly and southeasterly trades meet, and where rising currents of air are stronger than horizontal movements, is known as the *zone of equatorial calms.* The position of this zone of calms shifts a little with the sun, its center remaining near the thermal equator. The trade-winds are remarkably constant, and have been known for ages by navigators, who have often taken advantage of them. Sailing from the Canary Islands, to find Asia, Columbus came under the influence of the trade-winds, which bore him steadily across the Atlantic. For many years seamen from England followed this course.

The trade-winds blow only at and near the bottom of the atmosphere. Their upper limit has been observed on various mountains in South America, and on the Hawaiian Islands. In both cases it is about 10,000 feet. Fig. 389 shows why the trade-winds do not extend up to great heights. The isobaric gradients are poleward, except in the lower part of the air.

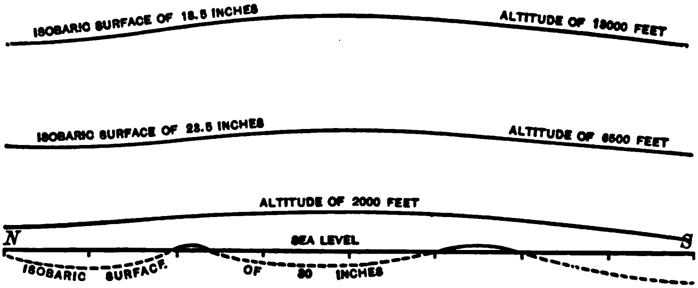
ISOBARIC SURFACE OF 18.5 INCHES
ALTITUDE OF 18000 FEET
ISOBARIC SURFACE OF 23.5 INCHES
ALTITUDE OF 6500 FEET
ALTITUDE OF 2000 FEET
N
SEA LEVEL
S
ISOBARIC SURFACE OF 30 INCHES

Fig. 389.—Slope of isobaric surfaces along meridians at various altitudes. (After Waldo.)

The westerly winds, on the other hand, extend much higher. Fig. 390 shows the directions of winds in the United States, at the bottom of the atmosphere, and in the upper air, as shown by the movements of high clouds. The movements indicated by the high clouds are to the eastward even when the lower winds blow in different directions.

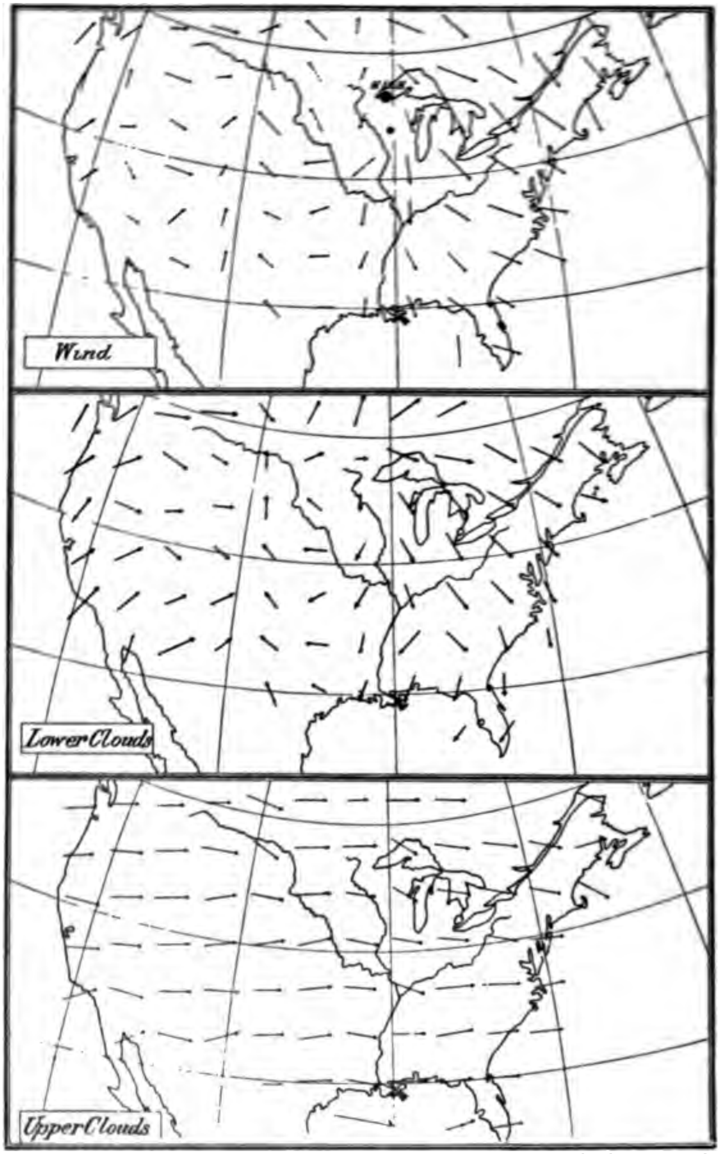

Fig. 390. Chart showing the direction of air movements at the bottom of the atmosphere (upper figure), at the horizon of the lower clouds (middle figure), and at the level of the upper clouds (lower figure) at a time when the pressure is high about Lake Superior. (U. S. Weather Bureau.)

The westerly winds of middle latitudes and the trades of low latitudes are the *prevailing* winds at the bottom of the atmosphere. They are sometimes called the *planetary winds.*

The high-latitude areas of low pressure. The permanent areas of low pressure over the northern oceans (Fig. 376) are another factor in the circulation of the air. There is a constant flow of air to these areas, and from them it rises and flows out above. This makes the circulation of the air still more complex.

Unequal heating of land and water. The unequal heating of land and water interferes with the circulation indicated in Fig. 388. *Land and sea breezes* and *monsoons* have already been cited (p. 357) as illustrations of the effects of this unequal heating.

The land and sea breeze may be understood by the help of Figs. 391 and 392. Fig. 391 represents low land along the seashore. We will suppose the land to be very low, so that the pressure of the air over it is not much affected by its altitude. The line *a b* is a few hundred feet above the surface of the land and water.

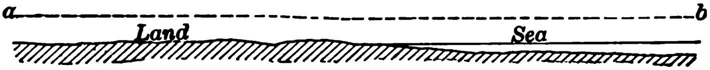

Fig. 391.—Diagram showing low land but a few feet above the sea and near its shore. The line *a b* may be taken to represent the upper surface of a zone of air a few hundred feet thick. The amount of air below *a b* may be assumed to be everywhere the same, and the pressure at its bottom is therefore uniform.

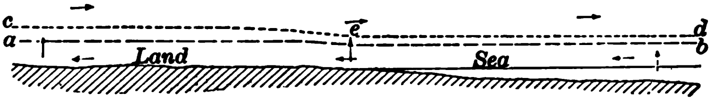

Fig. 392.—This figure represents the conditions shown in Fig. 391 after the heating of the land and water by the sun. The air below *a b* is expanded by the heat, and the tendency is for its surface to rise as shown by the line *c d*. This makes a barometric gradient, which results in movement of the air as explained in the text.

Let us suppose that at sunrise the air over land and sea is still. This would mean that the pressure is everywhere the same, at the same level. After sunrise, the land and the water are both heated, but the land is heated faster than the sea (p. 340). The air over both is warmed, but that over the land is warmed the faster. The air expands as its temperature rises, and that over the land expands more than that over the water.

At the beginning (Fig. 391) there was the same amount of air below the line *a b* at all places. After the sun has been shining a few hours, the air below *a b* (Fig. 391) will have expanded so as to occupy more space. Let us suppose that the air below *a b*, Fig. 391, has expanded so as to fill the space below *c e d*, Fig. 392. There is then the same amount of air below *c e d* at all points. Before movement begins, there is also the same amount of air above *c e d* at all points. But the air above *c e* has risen more than that above *e d*, and the air above *c e* has therefore been crowded together more than that above *e d*. A barometric slope has therefore been established between *c* and *d* above the line *e d*, and air will flow down it from *c* toward *d*, as shown by the upper arrows. When this has taken place, there will be less air over the land than over the sea, and a barometric gradient is thus established from the sea toward the land *at the bottom of the air*, as shown by the lower arrows (Fig. 392). This is the sea-breeze, which is strongest after the sun has been shining for some hours. At night the land cools more than the water. If the air over the water becomes warmer than that over the land, as it often does toward morning, the breezes shown in Fig. 392 are reversed. The breeze from the land to the sea at the bottom of the air is the *land-breeze*.

The daily land and sea breezes are not usually felt far from shore, and do not extend to great heights. At Coney Island, New York, the sea-breeze extends up to a height of about 500 feet, at times when its height has been determined. At some other places sea-breezes have been known to extend up 1,300 feet.

On the coast of Massachusetts the sea-breeze sometimes starts as early as eight o'clock, though more commonly not till an hour or two later. At first it advances inland at the rate of 3 to 8 miles per hour, and later more slowly. It penetrates inland only about 10 to 20 miles. On the coast of southern California, the land and sea breezes persist throughout the year, being much stronger in summer than in winter. Breezes corresponding to land and sea breezes are often felt about large lakes. Land-breezes are generally less well developed than sea-breezes.

The sea-breeze is of consequence, not only by lowering the temperature of the land in hot weather, but by bringing pure air to the land. This is of much importance along densely populated coasts.

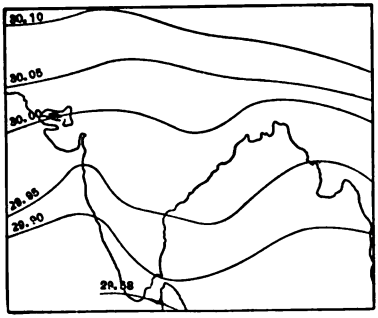

Fig. 393.

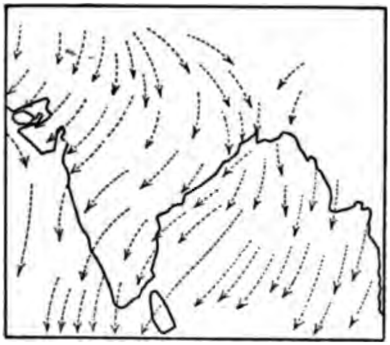

Fig. 394.

Fig. 393.—The isobars of India for January. (Bartholomew.)
Fig. 394.—Figure showing the direction of winds in India in winter. (Köppen.)

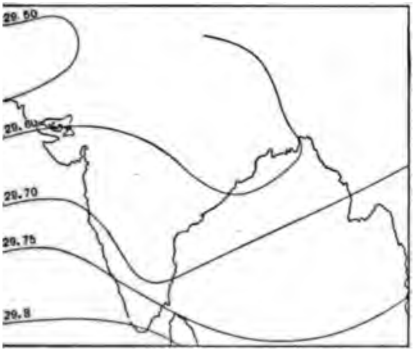

Fig. 395.

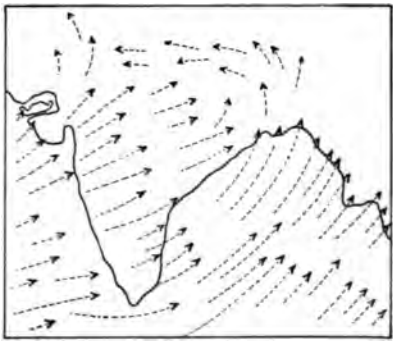

Fig. 396.

Fig. 395.—The isobars of India for August. (Bartholomew.)
Fig. 396.—The winds of India in midsummer. (Köppen.)

India affords a good illustration of the *monsoons*. This country is in the latitude of the northern trades, where easterly (north-easterly) winds should prevail. In Fig. 393 the gradient is from north to south, and the direction of the wind (Fig. 394) is in harmony with the planetary system (Fig. 388); but in Fig. 395 the isobaric gradient is to the northward, because the land is warmer than the sea, and the winds in the lower part of the air blow from sea to land (Fig. 396). That is, the planetary (northeast) wind is overcome during the hot season by the winds which result from the seasonal change of temperature. At the same season, the low pressure north of India, developed by the heat of summer, counteracts the high pressure common in this latitude, and the prevailing wind is displaced by seasonal winds blowing toward the area of low pressure. Figs. 397 and 398 show the isotherms for the same region at the corresponding seasons, and make clear the relation between pressure and temperature.

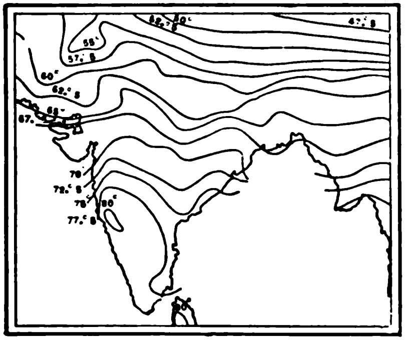

Fig. 397.

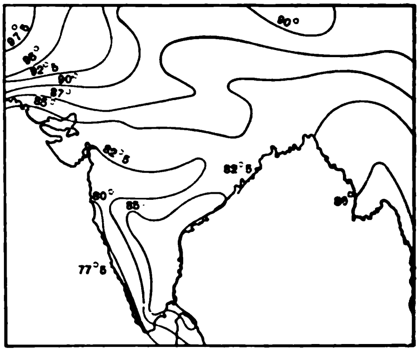

Fig. 398.

Fig. 397.—Isotherms of India for January. (Buchan.)
Fig. 398.—Isotherms of India for August. (Buchan.)

When the monsoon blows *with* the prevailing wind, as in western India in winter, the prevailing wind is strengthened; if the two are trying to blow in opposite directions, as in western India in summer, the stronger prevails. In Fig. 396 the monsoon wind has overcome the trade-wind proper to the region.

Spain, in the zone of westerly winds, affords another excellent example of the monsoon winds.

The general principle of the monsoon makes itself felt about the Great Lakes. At Chicago, which is in the zone of southwesterly winds, northeast winds predominate in spring, because the lake is then cooler than the land, and the winds blow toward the land and overcome the prevailing winds.

Besides the planetary winds, the seasonal winds (monsoons), and minor periodic winds (land and sea breezes, etc.), whose times of coming and going are more or less regular, there are numerous winds which blow at irregular times, and whose coming cannot be foretold long in advance. These irregular winds are the chief cause of the uncertain elements of the weather. Some of them are due to unequal temperatures, some to unequal amounts of atmospheric moisture, and some to other causes.

Irregular winds. Whirlwinds and tornadoes are examples of winds which have no regular times of coming. Both are due to strong convection currents which result from great heating of the land in small areas. Some larger whirls of air, such as the *tropical cyclones,* may be due to the same general cause. Winds of this class will be referred to in the next chapter.

Summary. We may now recall the chief points thus far studied in connection with atmospheric circulation. These are as follows:

(1) Above the lower part of the atmosphere there is a poleward movement of the air from low latitudes.

(2) There must be a return movement of air from high latitudes to low; but outside the extra-tropical belts of high pressure, this movement is not well defined in the lower part of the air.

(3) The extra-tropical high-pressure belts are the zones from which the dominant planetary winds at the bottom of the atmosphere start.

(*a*) These planetary winds tend to blow poleward and equator-ward in each hemisphere, from the belts of high pressure.

(*b*) They (and all other winds) are deflected to the right in the northern hemisphere, and to the left in the southern hemisphere, by the rotation of the earth, thus establishing the double trade-wind zone, with the equatorial calms in the center, and two zones of westerly winds, with tropical calms on the equator-ward margin of each.

(4) The simplicity of the system of planetary winds is inter-

fered with by the inequalities of temperature between land and sea in the same latitude. Because of these irregularities, the planetary winds are sometimes overcome by seasonal winds, such as the monsoons, or by daily breezes, such as land and sea breezes, and mountain and valley breezes.

Gradient, velocity, and directions of wind. The slope of an isobaric surface is its *gradient*. Gradient is differently expressed in different countries. In England the barometric gradient is said to be 1 when the difference of pressure is .01 of an inch in 17 miles. In the United States, barometric gradient is commonly defined as the difference in pressure at the same level between two points which are distant from each other the length of 1° of latitude. Thus if two places 5° apart in latitude have a difference of pressure of .5 inch, the gradient is .10 of an inch. Stated mathematically, $30-29.50=.50$; and $.50\div 5=.10$.

The greater the gradient, the greater the velocity of the wind. On the isobaric chart, high gradient is expressed by the crowding of isobaric lines. The crowding of such lines, therefore, means high winds. A gradient of .10 inch means a wind of about 30 miles an hour, and a gradient of .20 means a wind of about 55 miles an hour.

In general, the average velocity of winds is greatest in latitude 50° or thereabouts. The average velocity for the United States has been estimated at about 9.5 miles per hour, and for Europe 10.3. The velocity is greater over the sea than over the land, largely because the moving air is checked on land by friction with the uneven surface, with buildings, vegetation, etc.[1] It is also greater in the upper air than in the lower, for the same reason.

THE GENERAL CIRCULATION AND PRECIPITATION

Rainfall is of great importance to all plants and animals which live on the land. Few plants live in desert regions; and few animals live where plant life is scanty. Human industries, too, are much affected by rainfall, for no arid region supports a dense population.

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[1] Helmholtz has calculated that if the whole body of air were set in motion at the uniform rate of 20 miles per hour, it would take nearly 43,000 years to slow it down to 10 miles, as a result of friction.

Nevada, which receives but little rain, had, in 1900, only one inhabitant for each two and a half square miles. Less than one-thirtieth of the people of the United States live in the third of the country where the rainfall is less than 20 inches per year. The best of soil is not fertile unless adequately watered. Twenty inches of rain per year is generally considered to be the minimum for general agricultural purposes, but something depends on the temperature, something on the time of year when the rain falls, and something on the soil. The warmer the climate, the more the water needed. The total amount necessary is less if it falls when the growing crops need it most. If rainfall could be distributed just as farmers would like to have it, 10 inches would probably be enough in the middle latitudes of the United States. Water or snow falling at times when plants are not growing is, however, not worthless, for some of it remains underground, and is reached by the roots of plants at a later time.

Land which can be irrigated does not depend directly on rain and snow; but the water used in irrigation is derived from rainfall, though the fall is often far from the place where the water is used. Only a small part of the arid land of our country can ever be irrigated, because the amount of water which can be carried to the arid land is limited.

The distribution of rainfall is influenced largely by the winds, which carry much moisture from the places where it is evaporated to the places where it is precipitated. Prevailing winds, periodic winds, and winds which come at uncertain times (*aperiodic winds*), all help to determine where rain falls, how much falls, and at what times of the year.

To know what the rainfall (or snowfall) of any given region will be, it is needful to know (1) what winds affect it, (2) the topography of the surafce over which the winds have already blown before reaching it, and (3) the topographic situation and relations of the place itself.

Rainfall in the zone of the trades. In the trade-wind zones, the winds are blowing from higher to lower latitudes, and therefore, on the average, from cooler to warmer latitudes. As the air is warmed, it may take more moisture. So long as the trades blow over the sea, therefore, they do not ordinarily give rain. Where they blow over low land, which in this latitude is generally warmer than the sea, they take moisture, but do not drop what they have. It follows that on the sea, and on low lands, like the Sahara, the trade-winds are "dry." A part of Australia lying in the belt of southerly trades is also dry.

If, however, the air of the trades is forced up over mountains, it is cooled, and some of its moisture may be condensed and fall as rain or snow. *The windward sides of high mountains in the trade-wind zone have heavy rainfall.* An illustration is afforded by the east side of the Andes Mountains in the trade-wind zone. The rainfall is there heavy (Fig. 399). Another illustration is afforded by the volcanic cones of the Hawaiian Islands. The trade-winds yield little rain to their lower slopes, but forced up over the mountains they yield abundant moisture at higher levels. These levels are readily seen by the change in vegetation where the rainfall becomes abundant.

After the air of the trades passes over a mountain range, it descends, and is warmed both by contact with the warm surface and by compression. It therefore takes up moisture. The leeward sides of mountains in the trade-wind zones are therefore regions of little precipitation. The west slope of the Andes Mountains in the zone of the trades is an example (Fig. 399). A high mountain range on the east side of a continent in the zone of the trades would make all the land to the west of it dry, unless that area had mountains as high as the first range.

In the zone of *equatorial calms* (p. 389), also called *doldrums*, the temperature is high, and the air, warmed by the sun daily, expands and is crowded upward by the less warm air which comes in from the zones of the trades. As the air rises, it expands and cools, and often gives up some of its moisture. In this zone, therefore, there are likely to be daily rains from cumulus clouds at the time of day when the upward currents are strongest,— that is, in the afternoon. Since the doldrums shift north and south a few degrees yearly with the shifting of the thermal equator, a place near the equator which receives the daily rains during one season

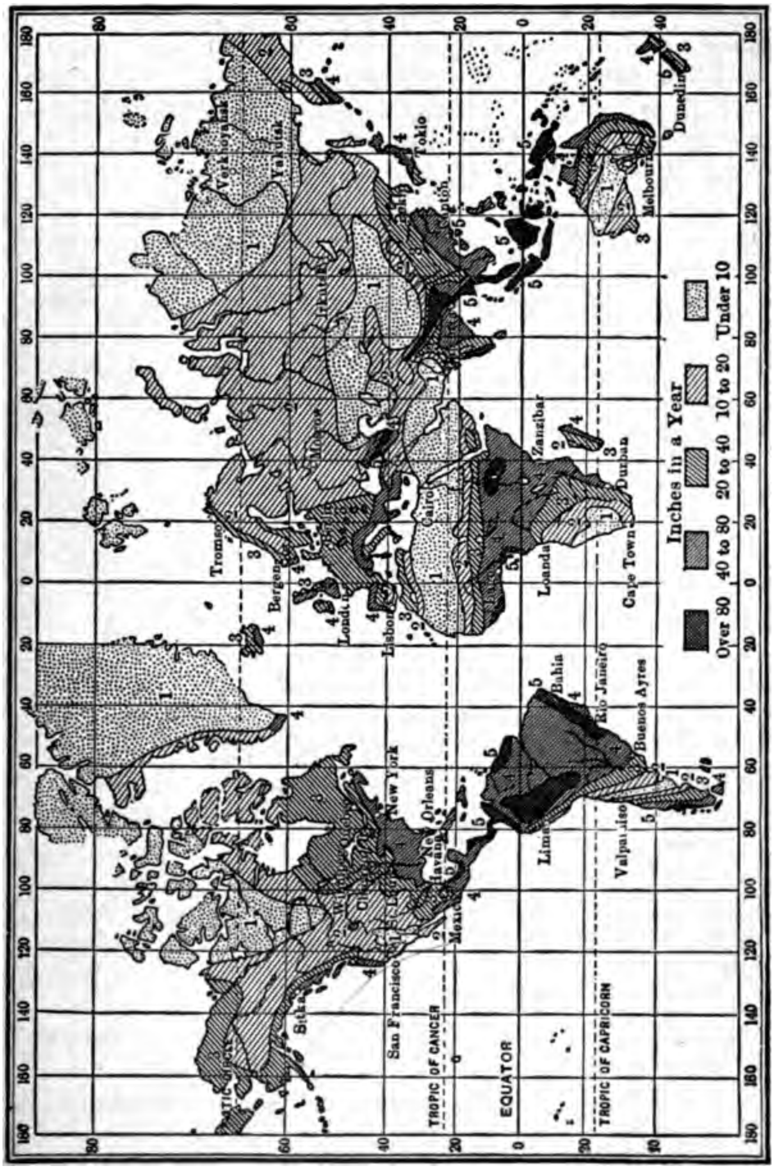


Fig. 399.—Map showing the precipitation for the world.

may be without them at another time of the year. Such places have a wet and a dry season each year.

Rainfall in the zones of the prevailing westerlies. The principles which apply to the trade-wind zones apply also in the zones of the westerly winds. These winds are, on the whole, blowing from lower to higher latitudes, and so are being gradually cooled. They might therefore yield some moisture, even at sea-level or on low land, and especially on land in the winter season. The heat of the land in summer often prevents condensation and precipitation of the moisture in the westerly winds until the air has moved far to poleward. But when such winds cross mountains they yield moisture to their windward slopes and summits, and become dry on the leeward slopes. A high mountain range on the west side of a continent in the zones of westerly winds would tend to make all the low land to the east of it dry, unless the moisture came from some source other than the westerly winds.

From these principles we may understand the rainfall of the United States, so far as it depends on planetary winds. The prevailing winds, for most of the country, are from the southwest. Coming to the land from the Pacific Ocean, these winds find the land cooler than the ocean in winter, and warmer in summer. In winter they yield moisture, even at low levels. This gives the low lands of California their wet season. As the winds blow on across the mountains back from the coast, they yield more moisture, so that all the area west of the top of the first high ranges, the Sierras at the south and the Cascades at the north, is supplied with rain and snow in the winter season. As the winds blow beyond the Sierra and the Cascade mountains, the air descends and becomes warmer, and therefore dry. East of these mountains lie the semi-arid lands of the Great Basin, with its Great Salt Lake, and of eastern Oregon and Washington.

When these winds reach the higher parts of the Rocky Mountains, which are higher in many places than the mountains farther west, they again yield some moisture. But farther east, all the way to the Atlantic, these winds would remain dry, for they cross no more high mountains, and they do not generally go far enough *north to* reach a temperature as low as that of the mountains they have passed. For some distance east of the mountains the rainfall is slight; but east of central Kansas and Nebraska the lands are well supplied with moisture. It is therefore clear that something besides the westerly winds brings rainfall to this region. This factor is the aperiodic *cyclonic* winds, to be studied in the next chapter.

The winds which blow from the Pacific to the continent in summer have a different effect upon rainfall. At this time of year, the winds find a temperature on the low lands higher than their own. They are therefore "dry" in this region, and give to much of California its dry season. Blowing inland, these winds reach mountains so high that the temperature is low enough to cause condensation and precipitation, even while the low lands to the west are dry.

Farther north the case is somewhat different. In Washington, for example, the mountains near the coast are high enough to occasion precipitation even in summer. In Alaska, where some of the mountains are always covered with snow, precipitation is heavy in the summer, and at high altitudes it often falls as snow instead of rain.

Monsoon winds may yield much moisture. In general, they blow toward warmer regions, and so should be dry; but once started, they are sometimes forced up over high mountains, and precipitation follows. The heaviest rainfall on record, on the southern slopes of the Himalayas, is due to monsoon winds. Numerous famines in India have followed the failure of the monsoon rains. The famine of 1876–78 affected 58,000,000 people directly, and is estimated to have cost 5,000,000 lives. As in the case of the planetary winds, it is the windward sides of the mountains which receive the heavy precipitation from the monsoons. It is clear, therefore, that *the windward sides of high mountains are places of heavy rainfall and snowfall.*

Land and sea (or lake) breezes (daily) rarely yield much rain, though they often give rise to fogs when they blow from the warmer water to the cooler land. Such fogs may occasionally be seen, as at Chicago in the late autumn or early winter, advancing with a wall-like front, varying from a few feet to many scores of feet in height. Valley breezes, also, sometimes give rise to heavy showers.

CHAPTER XVII

WEATHER MAPS

Fig. 400 is a weather map of the United States for January 12, 1899. Like other weather maps, it shows (1) isobars, which indicate the distribution of atmospheric pressure, (2) the direction of the winds (shown by arrows) in various parts of the country, (3) the condition of the air with reference to cloudiness, rainfall, snowfall, etc., at all points, and (4) isotherms, which indicate the temperature throughout the country.

Weather maps are made by the Weather Bureau, a branch of the National Department of Agriculture. They are prepared in various offices of the country, where telegrams are received daily from numerous stations in different parts of the country. Each telegram tells the pressure, the temperature, the direction and velocity of the wind, the cloudiness, the rainfall and the snowfall, etc., at the station whence the telegram is sent. These stations are established and maintained by the Government.

Explanation of the Map

1. **Isobars.** The isobars of the map are the full lines. The map shows a range of pressure from 30.6 inches in the area centering about the Hudson River Valley, to 29.5 in North Dakota. The pressure is more than 30 inches in the eastern half of the country, less than 30 inches in the western interior, and more than 30 inches in an area near the Pacific coast.

The isobar of 30.6, in the eastern part of the United States, is a closed line. Outside of it is the isobar of 30.5. Since the pressure rises as the isobar of 30.6 is approached from outside, it is inferred that it continues to rise after this isobar is passed. The area inside it, therefore, has a pressure of more than 30.6 inches,

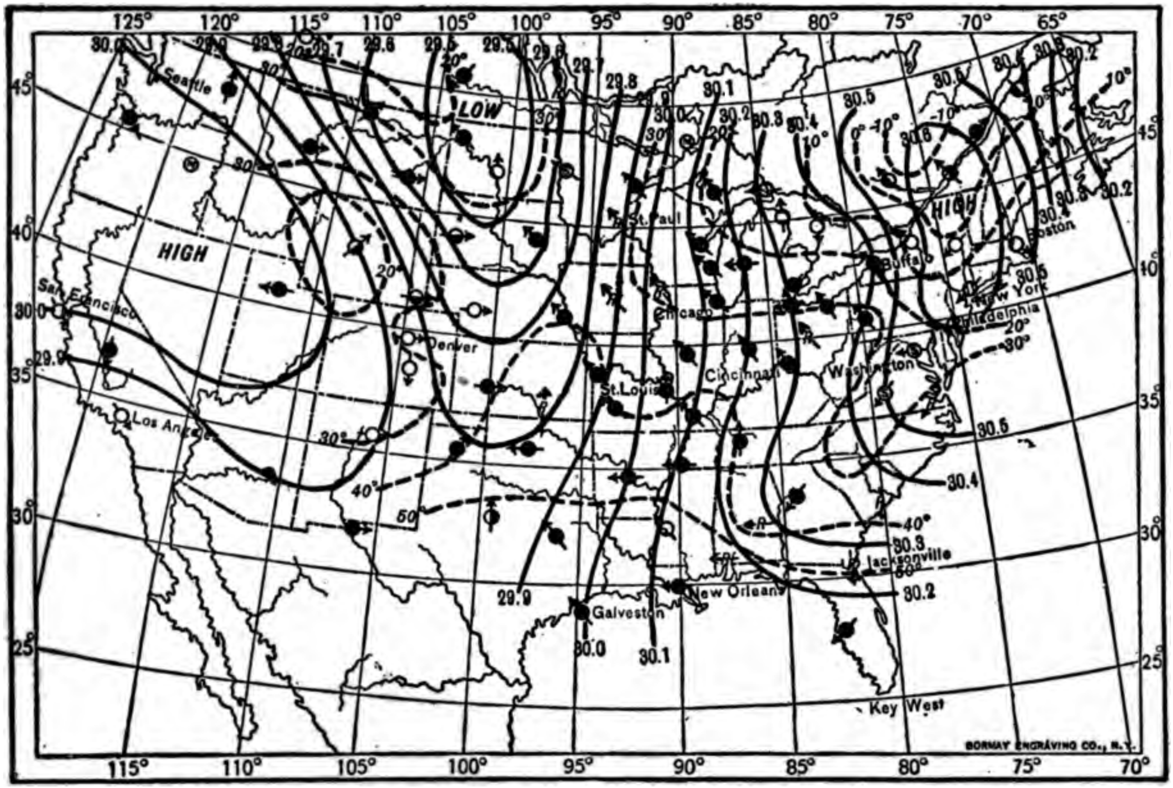


Fig. 400.—Weather map of the United States for January 12, 1899. The full lines are isobars, the dotted lines isotherms. (U. S. Weather Bureau.)

but not so much as 30.7 inches, else another isobar would have been represented. Similarly, all points between the isobars of 30.6 and 30.5 have pressures between those indicated by these figures. The pressure is higher near the former isobar, and less near the latter.

The center of this high-pressure area is marked "high." "High" on the weather map means an area where the pressure is distinctly higher than that of its surroundings, and generally exceeds 30 inches, and the word is placed in the center of such an area.

To the west of the high over the Hudson River Valley the pressure decreases steadily to North Dakota, where there is a center of low pressure, marked "low." "Low" means an area in which the pressure is less than that of its surroundings, and generally less than 30 inches. On the weather map the word is placed at the point in such an area where the pressure is lowest.

The isobar of 29.5 about the low in North Dakota is a closed line. Since the pressure is becoming less as this line is approached, it is inferred that the pressure at all points within this isobar is less than 29.5, though nowhere so low as 29.4. West of the low the pressure increases. The pressure in the high near the Pacific coast is not so great as that in the high over the Hudson Valley.

Most weather maps show both lows and highs, or at least one of each. Since this is the case, the atmospheric pressures are generally unequal in different parts of the country.

2. **Wind.** Wherever barometric pressures are unequal, isobaric surfaces are uneven. The arrows on a weather map (Fig. 400) show the direction of the winds, which blew as the arrows fly. Their positions are based on the reports received at the map-making offices, from the stations of the Weather Bureau. On January 12, 1899 (Fig. 400), winds were blowing away from the highs in the east and west, respectively, and toward the low in the northwest. The movements of air out from an area of high pressure constitute an *anticyclone*, and the movements in toward a low constiute a *cyclone*. A cyclone is one type of a *storm*. The winds in a cyclone are not always strong,— rarely strong enough to be destructive. The violent wind-storms, popularly called cyclones, are here called ***tornadoes***.

Winds do not blow straight out from the anticyclonic centers, nor straight in toward the cyclonic centers. They may *start* straight out from the center of each high, but they are turned (deflected) toward the right in the northern hemisphere, as most of the arrows about the highs show. Similarly the winds which blow toward the cyclonic centers are deflected to the right in our hemisphere, as most of the arrows about the lows show.

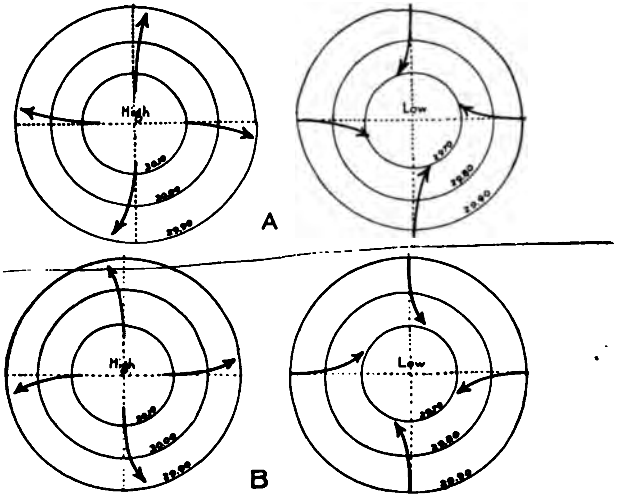


Fig. 401—*A* shows the circulation of air about a low and a high in the northern hemisphere; *B* shows the same in the southern hemisphere.

In the southern hemisphere the winds are turned to the left instead of to the right (Fig. 401, B).

The strength of the winds at various points may be inferred from the map. The distance from the center of the high in the east (Fig. 400) to Lake Michigan is about 800 miles. The difference in pressure is about .5 inch. This gradient would cause a wind of about 12 miles an hour—a fresh breeze—between these points. The velocity of the wind blowing from Michigan to North Dakota is about the same, while the velocity of the wind from Texas to North Dakota is much less. Where isobars are crowded, the gradient is high and the winds strong. Where they are widely separated, the gradient is low and the air-flow gentle. The winds in cyclonic storms occasionally attain a velocity of 40 to 60 miles an hour; but the average is very much less.

As the air moves in toward the center of a cyclone, it also moves spirally up. This upward movement is of great consequence in its effect on precipitation, as we shall see. The upward and outward course of the air in a cyclone is shown in Fig. 402, which represents a vertical section of a cyclone. It shows that the outflow above is chiefly to the eastward, the direction in which prevailing winds blow.

3. **Cloudiness, precipitation, etc.** The open circle on the shaft of an arrow (Fig. 400) indicates clear skies, the half-blackened circle (as in Wyoming) shows that the sky is partly cloudy, while the black circle (as in Illinois and Indiana) indicates general cloudiness. Where *R* appears on the arrow, as in Iowa and Alabama, rain is falling. Where *S* appears in the center of the circle on the arrow it shows that snow is falling, as in northwestern Minnesota, Virginia, and Maryland.

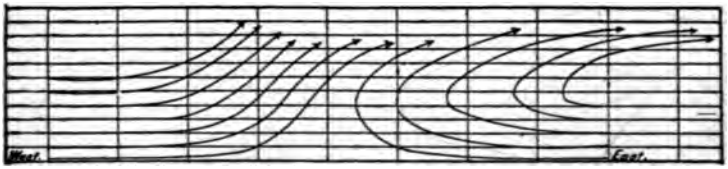


Fig. 402.—Diagram illustrating the general position of air currents in a cyclone of intermediate latitudes, and the fact that the upper air moves mostly toward the east, in the direction of the prevailing winds. (U. S. Weather Bureau.)

This weather map shows that more or less precipitation accompanies the cyclone, and this is often the case. Whether the precipitation takes the form of rain or snow depends on the temperature (p. 366).

4. **Temperature.** The dotted lines of the weather map are isotherms. The isotherm of 50° (Fig. 400) crosses the Gulf States, and south of it the temperature is above 50°, but not so high as 60°, within the area of this map. The isotherm of 40° is very

crooked, extending from Georgia to Nebraska, and thence to Arizona. All points between this isotherm and that of 50° have a temperature intermediate between 40° and 50°.

The isotherm of 30° is still more irregular. Dubuque, Ia., Chicago, Cleveland, Charlotte, N. C., and Norfolk, Va., have about the same temperature. An isotherm of 30° also extends from Idaho to New Mexico by a crooked course, while a third isotherm of 30° appears about the low.

The isotherms of Fig. 400 show two distinct features: (1) they have little relation to parallels, and (2) the isotherms bend northward where the pressure is low, and southward where the pressure is high. This last feature is shown in most of the weather maps which follow; but on many of the maps the isotherms follow the parallels more closely than in Fig. 400.

The temperature, the pressure, the winds, the cloudiness, the rain, etc., are the elements of the weather. All these things being shown on the above map, it is appropriately called a *weather map.*

The lows and highs are sometimes much more pronounced than those shown in Fig. 400. In Fig. 403 the low is more pronounced, the pressure ranging from 29 at the center to 30.1 in the east, and to 30.5 in the west. So great a range of pressure within the United States is not common. The isobars are closer together in this figure than in Fig. 400, and therefore indicate stronger winds. Cloudy skies prevail in the southeastern part of the cyclone, and snow is falling at some points (Montreal and Duluth). The map also shows great ranges of temperature in areas not far apart. Thus there is a temperature of 30° F. at Sault St. Marie, and a temperature of 10° at Winnipeg, but little farther north. Montreal has a temperature higher than that of Santa Fé. As in the preceding weather map, low temperature goes with high pressure, and high temperature with low pressure.

Fig. 404 shows a very irregular low. The winds blow toward it, but are deflected to the right of its center. Cloudiness prevails over a great area about the cyclone, and snow and rain are falling at some points. The low of this map is over the larger part of the country. Its diameter, measuring from the 30-inch isobar on the east to the 30-inch isobar on the west, is about 1,800

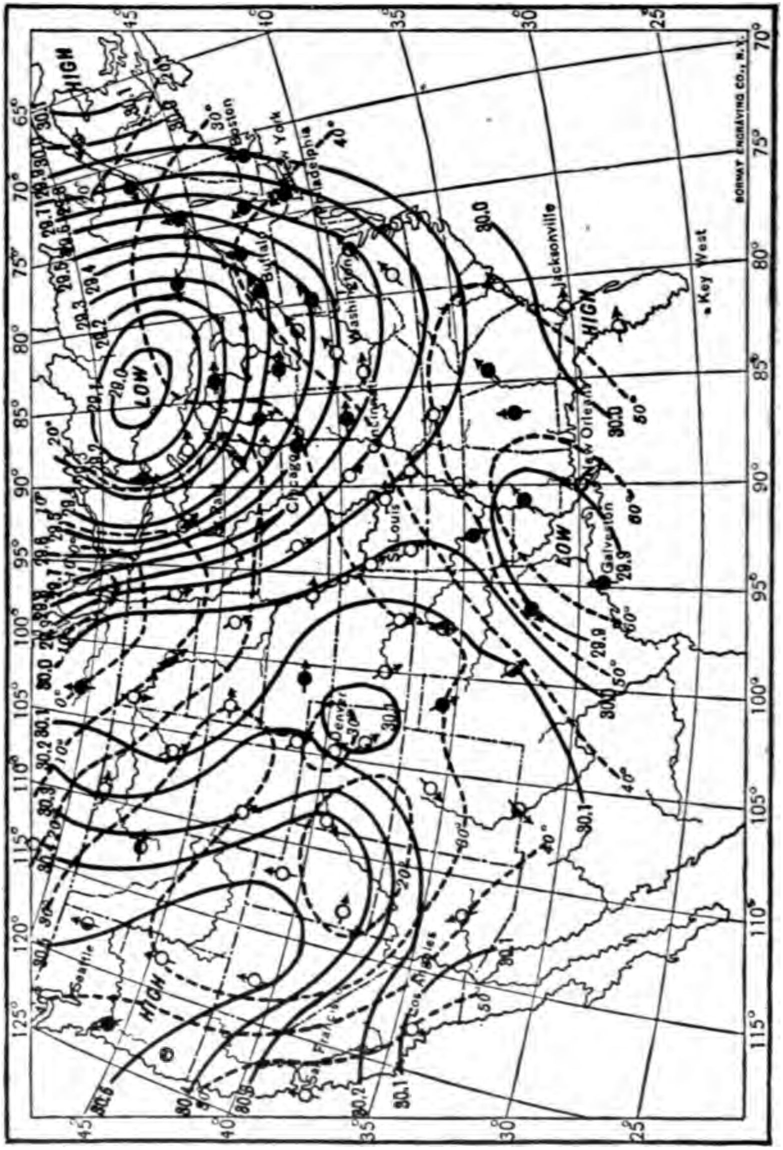


Fig. 403.—Weather map for January 10, 1901. (U. S. Weather Bureau.)

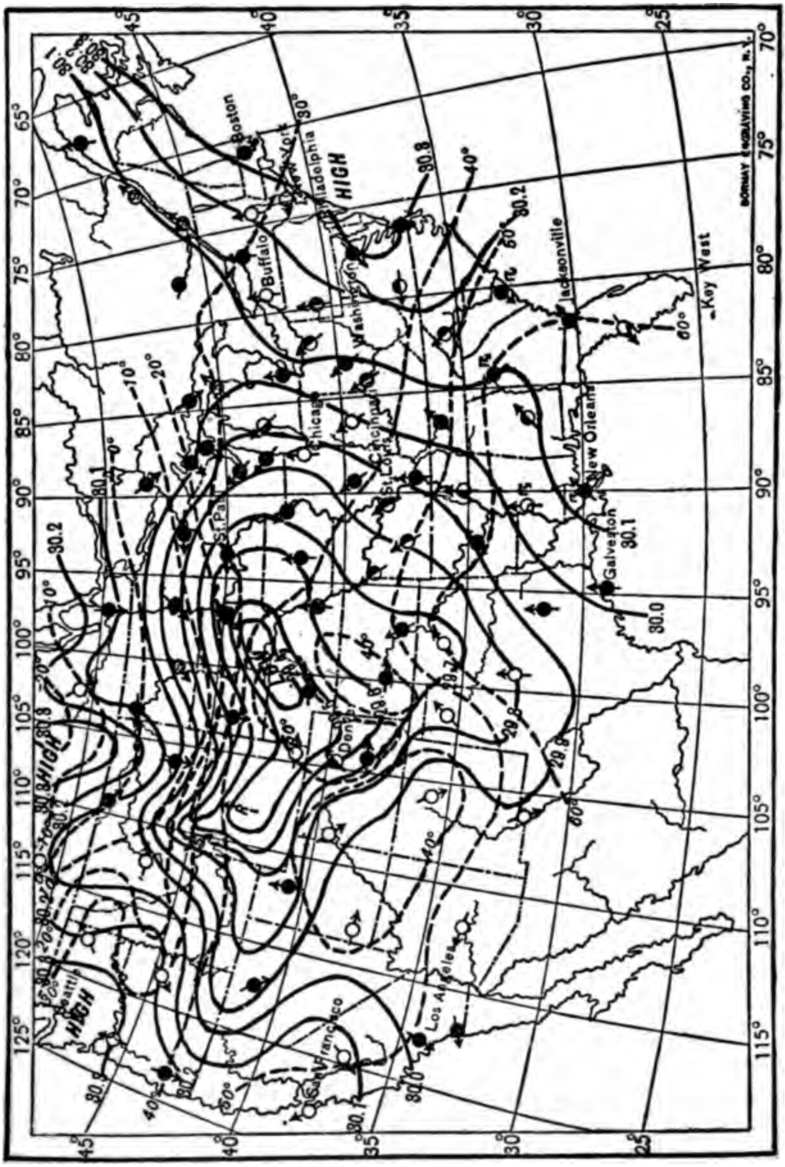


Fig. 404.—Weather map showing a large asymmetrical low, March 2, 1904. (U. S. Weather Bureau.)

miles. The isotherms bend northward on the south side of this low, and south about the high north of Montana.

Highs as well as lows may have great area. Fig. 405 shows a high, or anticyclone, more than 2,000 miles across, with a great range of pressure. The isotherms of this chart, like those of the preceding, stand in very definite relations to the isobars. Denver, in the anticyclone, is about 30° colder than the southern part of Maine, which is 3° farther north, but in a cyclone.

Around all the preceding cyclones some precipitation is indicated, while around most of the anticyclones there is an absence of precipitation. The chief reason for rainfall or snowfall about a low is as follows: The inflowing air produces an upward spiral current, and the rising air expands and is cooled (p. 347 and Fig. 402), and so gives up some of its moisture. A less important reason is that the air coming into the cyclone from the south travels from a warmer to a cooler latitude. The change in temperature which results may be the cause of some precipitation. This is most likely to occur in the southeast part of the cyclone, because the wind blowing toward the center of the storm from the south turns to the east (*A*, Fig. 401). The prevailing winds which influence the direction of outflow in the upper part of a cyclone (Fig. 402) tend to carry the rainfall to the east of the center.

In the anticyclone there is a descending spiral movement of air. The descending air comes from an altitude which is colder than that at the bottom of the atmosphere, and hence brings a low temperature. Since the air is condensed and warmed as it comes down, the winds from anticyclones generally bring clear weather; but the cold air moving down and out from an anticyclone may mingle with the warm air about it, so as to cause some of the moisture of the latter to condense, giving rise to clouds, or even to precipitation.

Movements of cyclones and anticyclones. The highs and lows do not remain in the same place from day to day. This is shown by Figs. 406–411, which are the weather maps of six successive days. In these figures precipitation is shown by shading.

In Fig. 406 there is (1) a low along the Atlantic coast; (2) a high central over Iowa; (3) a feeble low north of Montana; and

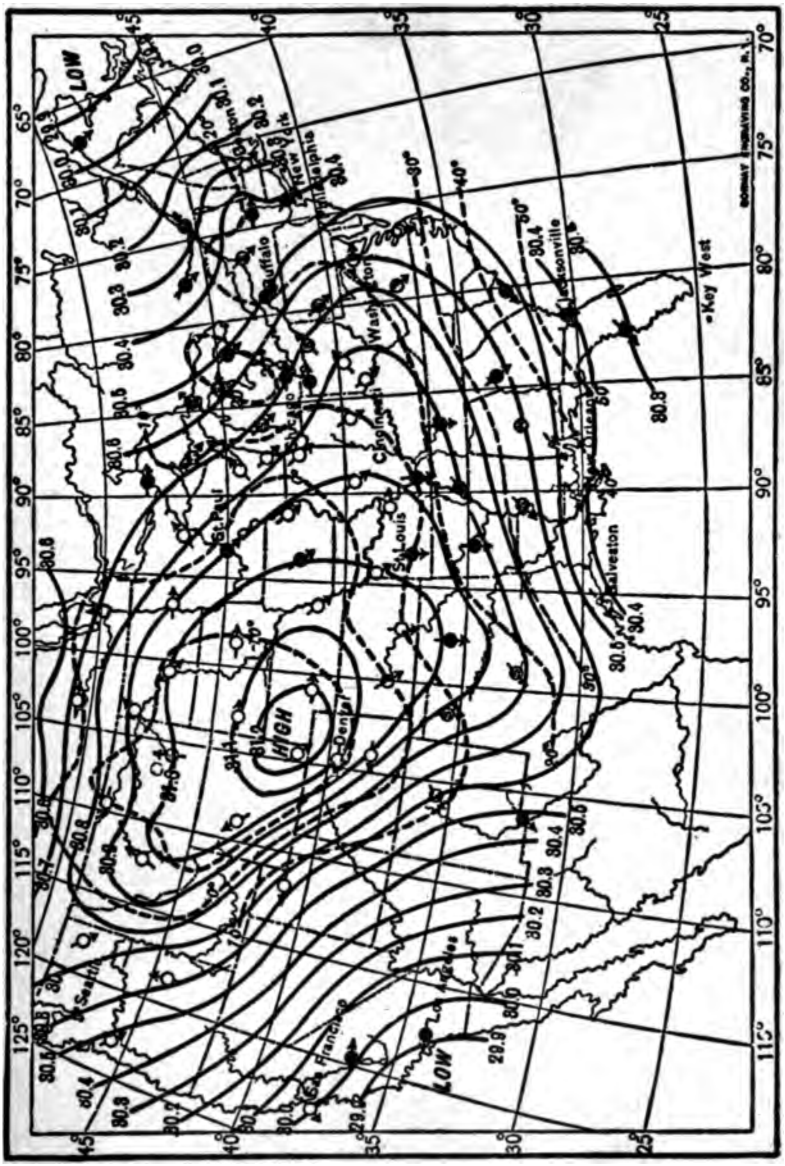


Fig. 405.—Weather map for December 9, 1898, showing a high of great area. (U. S. Weather Bureau.)

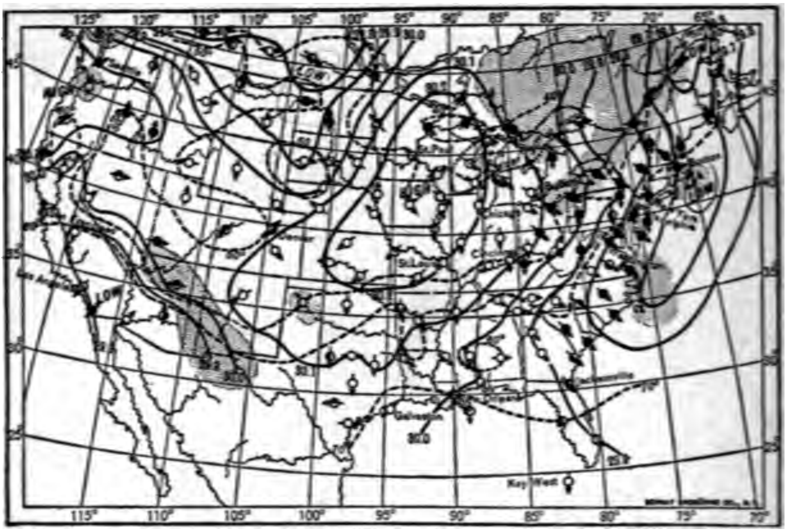


Fig. 406.—Weather map for September 24, 1903. The shading dots on this and succeeding maps represents precipitation. (U. S. Weather Bureau.)

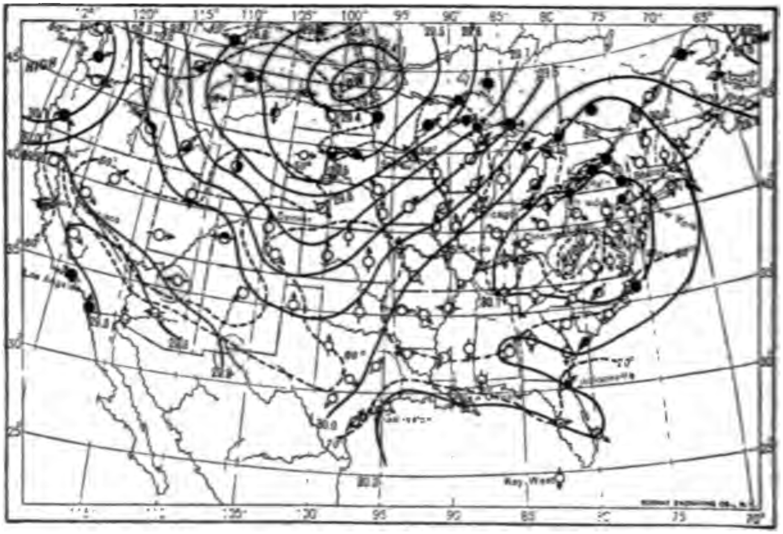


Fig. 407.—Weather map for September 25, 1903. (U. S. Weather Bureau.)

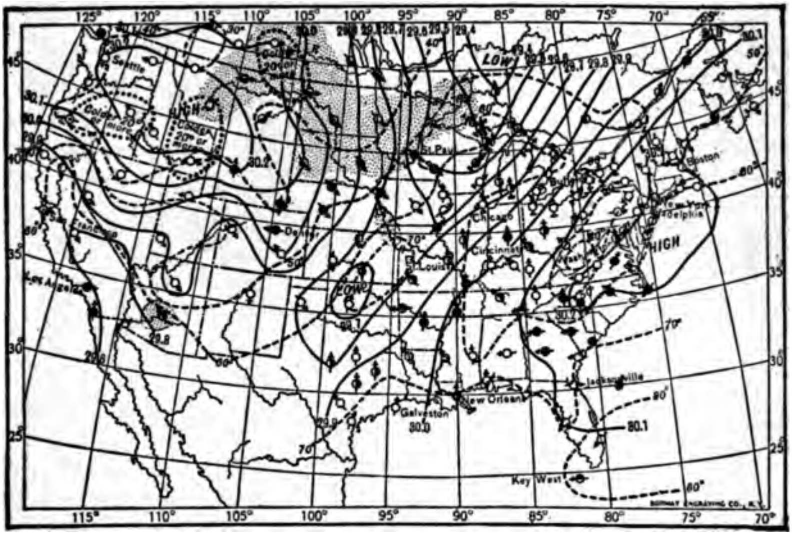


Fig. 408.—Weather map for September 26, 1903. (U. S. Weather Bureau.)

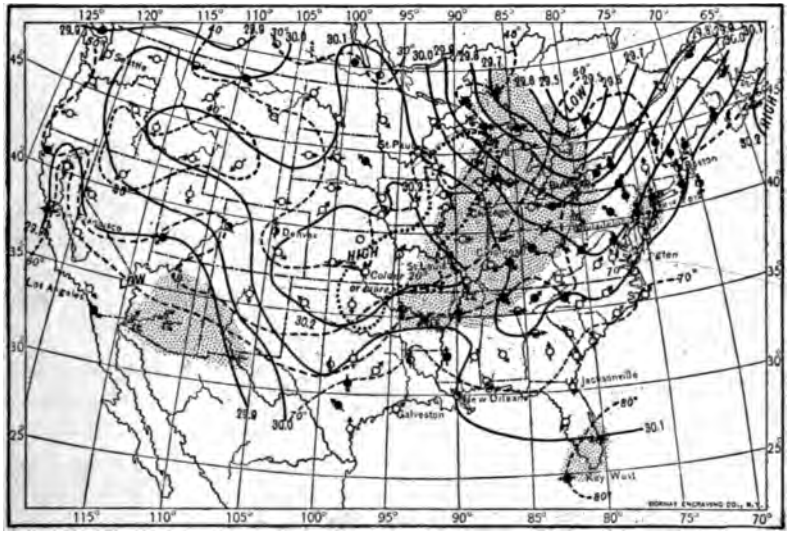


Fig. 409.—Weather map for September 27, 1903. The symbol which appears in central Arkansas and western Tennessee indicates a thunderstorm. (U. S. Weather Bureau.)

(4) a high in Oregon. The map of the succeeding day (Fig. 407) shows (1) that the low of the St. Lawrence Gulf has disappeared (moved to the east); (2) that the high of the interior has moved to West Virginia; (3) that the low which was north of Montana has moved to Dakota; while (4) the high of the Oregon coast remains about where it was. The map of the next day (Fig. 408) shows (1) that the high of the Virginias has moved on, but not so far as on the preceding day; (2) that the low which was over North Dakota is now north of Lake Superior; (3) that the high of Oregon has moved east to Idaho and Montana; and (4) that a weak low has developed in Oklahoma. The map of the 27th (Fig. 409) shows (1) that the high which was over the Virginias has disappeared, presumably to the east; (2) that the low which was north of Lake Superior is now north of Lake Ontario; (3) that the high of Montana has moved southeast to Kansas; (4) that the weak low (of Fig. 408) in Oklahoma and Indian Territory has disappeared; and (5) that another feeble low has appeared in southern California. The succeeding map (Fig. 410) shows that all the highs and lows of the preceding day have advanced in a general easterly direction. Fig. 411 shows that the two lows of Fig. 410 near the Pacific have united, the southerly one having moved over to the more northerly, — a not uncommon occurrence.

From Figs. 406 to 411 we may calculate the rate of movement of the highs and lows. Thus, from the 25th to the 26th (Figs. 407 and 408), the low at the north moved about 1,200 miles. From the 26th to the 27th, about half as far; and from the 27th to the 28th, about 800 miles. The average progress of cyclones in the United States is a little less than 29 miles per hour (about 700 miles per day); that of anticyclones somewhat less.

The rate of progress of the storm is not the same as the velocity of the wind. The velocity of the wind depends on the isobaric gradients. A weak cyclone, that is, a cyclone in which differences of pressure are not great (*e. g.* the one in Oklahoma, Fig. 408), gives rise to weak winds, even though the center of the storm moves rapidly. A strong cyclone, that is, one in which the differences of pressure are great (Fig. 403), gives rise to strong winds, even though the cyclone itself moves forward slowly.

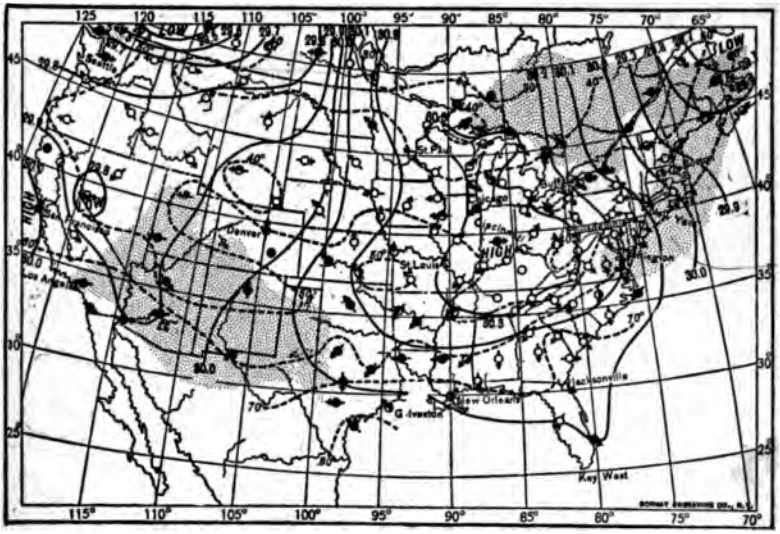


Fig. 410.—Weather map for September 28, 1903. (U. S. Weather Bureau.)

1200 600 500

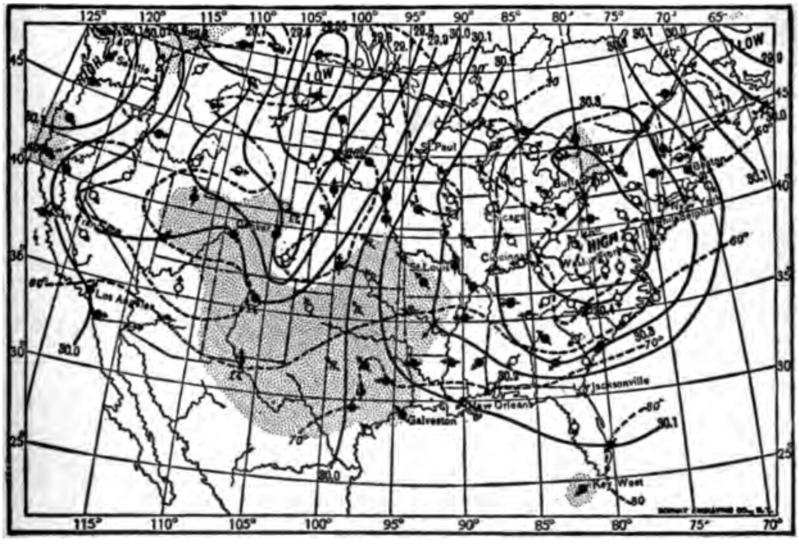


Fig. 411.— Weather map for September 29, 1903. (U. S. Weather Bureau.)

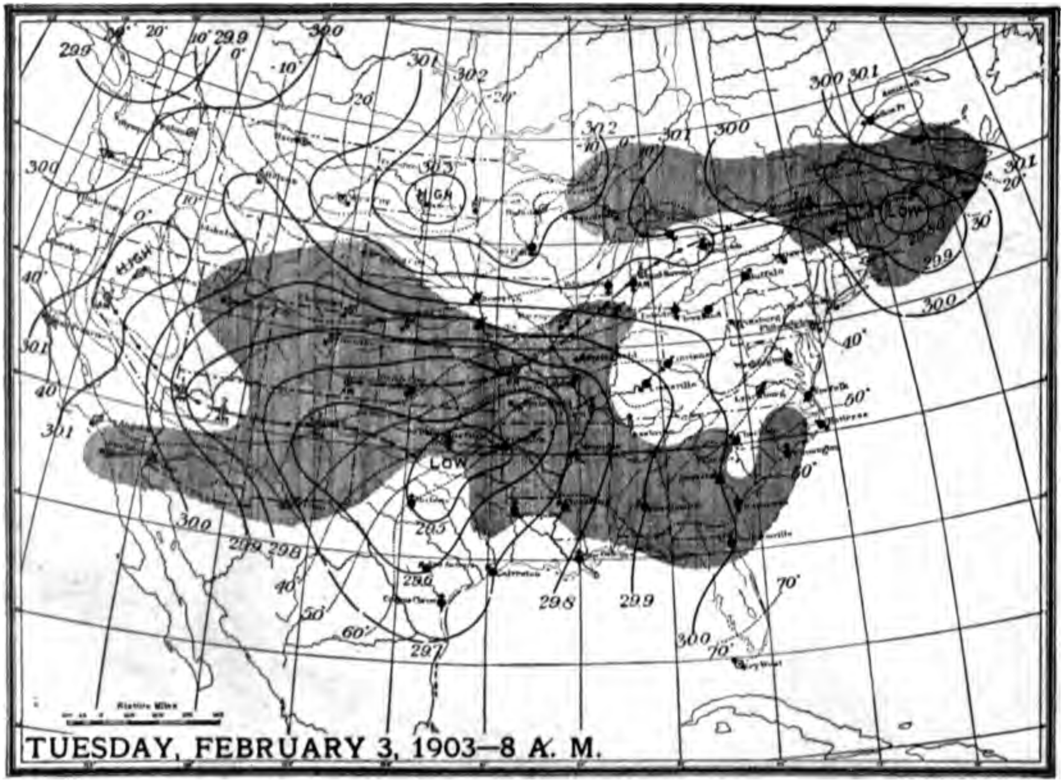


Fig. 412.—The rows of arrows to the west of the cyclones show their courses. (Cox, U. S. Weather Bureau.)

The course of a cyclone may be shown on a single map, as in Fig. 412. The row of arrows shows that the low of Maine has moved from Colorado, while that of Indian Territory has advanced from Nevada. The shading indicates precipitation.

The highs and lows of the preceding weather maps have all moved in a general easterly direction, but the highs have moved rather more to the south of east than the lows. The mean tracks of cyclones and anticyclones for the United States are shown in Fig. 413, the heavier lines showing the average paths of anticyclones, and the lighter lines the tracks of cyclones. The average direction of the cyclone in our middle latitude is about N. 80° E., or 10° north of east. The anticyclones have a slightly more southerly course.

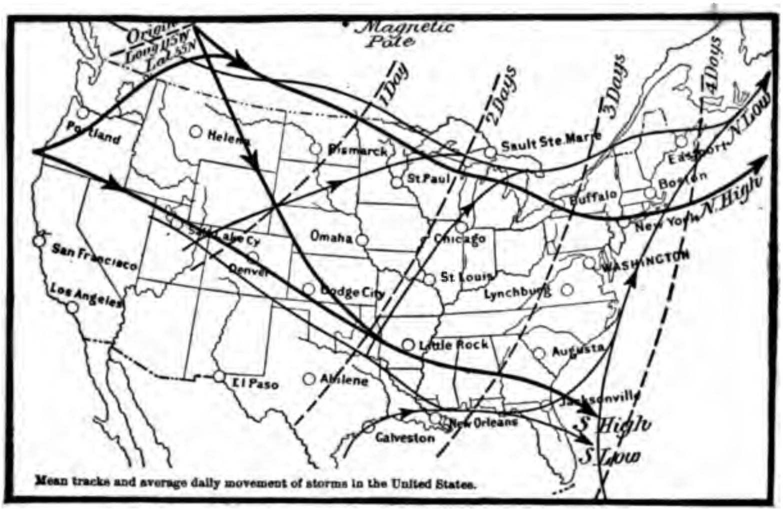


Fig. 413.—The heavier lines show the tracks of anticyclones, and the lighter lines the paths of cyclones. Off the South Atlantic coast, anticyclones are likely to turn northward. (U. S. Weather Bureau.)

Some anticyclones enter the United States from the Pacific, while others start north and northwest of Montana, or at any rate are first known there. They take either a northerly or a southerly route across the continent. The former extends through the

Great Lake region to southern New England, while the latter (less common) reaches the Atlantic or the South Atlantic coast. Anticyclones entering from the Pacific may take either of these courses, and those originating in the northwest may do the same, as shown by the figure.

Cyclones make their first appearance in various places. More of them originate near the places where anticyclones start than in any other place; but not a few appear first in Colorado, the Great Basin, in Texas, and elsewhere. Those starting in the northwest usually pass through the Great Lake region to northern New England. Those starting farther south may follow a southerly course to the Atlantic, or may pass to the northward. Tropical cyclones, to be mentioned later, sometimes reach the Gulf of Mexico from lower latitudes, and follow the coast thence to the northeast.

Still another set of lines in Fig. 413, marked *1 day*, *2 days*, *3 days*, and *4 days*, show the average rate of daily progress of the storms which come in from the northwest on successive days.

The passage of a cyclone or anticyclone involves a change in the direction of the wind. Thus in Fig. 407 the wind at St. Paul is southeasterly, though this city is in the zone of westerly winds. The next day, after the storm center has moved forward to a position northeast of St. Paul (Fig. 408), the wind is northwesterly. In the zone of westerly winds, an east wind is often the first indication of an approaching cyclone; and since a cyclone often brings rain, the east wind is generally taken as a sign of rain throughout much of the United States.

Cyclones do not affect the air to great heights. Even when the great whirl or eddy is 2,000 miles across, as is sometimes the case, its height (depth) is rarely more than 4 or 5 miles.

Winds incidental to cyclones and anticyclones. During the passage of a cyclone air is often drawn from warmer (lower) to cooler (higher) latitudes. In midsummer this often gives rise to the *hot wave*, though hot waves are not always closely associated with cyclones. Similar winds are known as the sirocco in the western Mediterranean region, and they go by other names elsewhere.

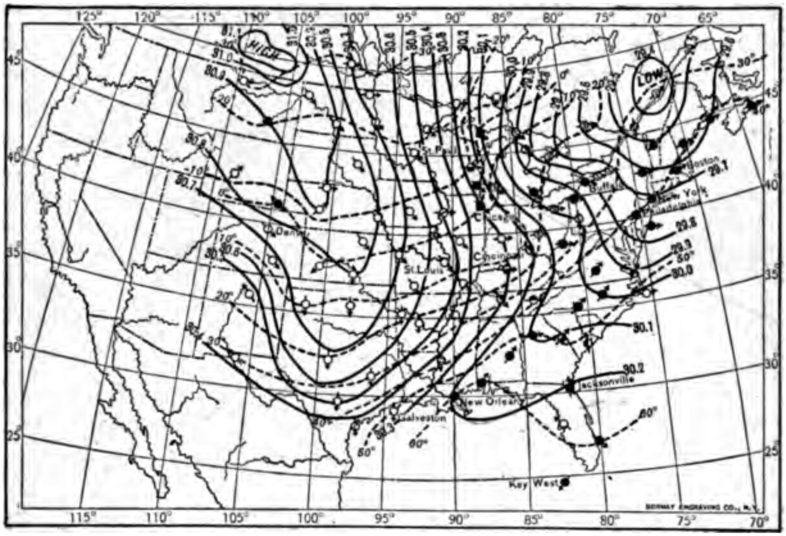


Fig. 414.—Map showing the cold wave of January 3, 1896. (U. S. Weather Bureau.)

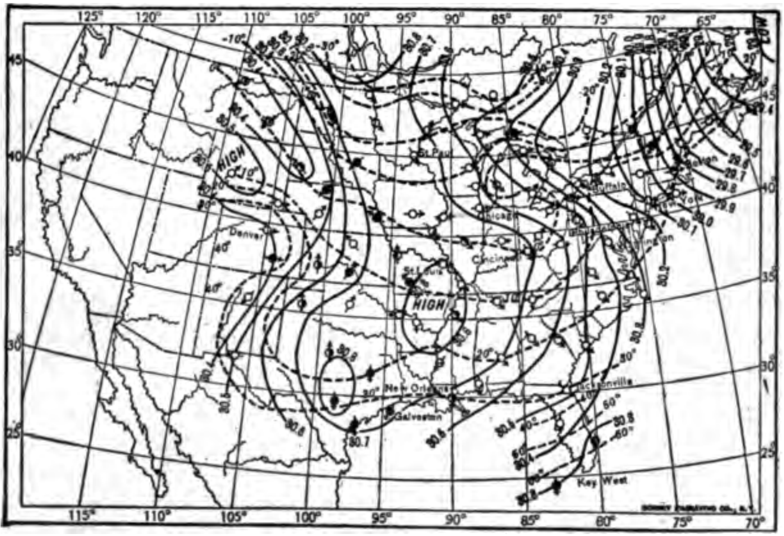


Fig. 415.—Map for January 4, 1896, showing the progress of the cold wave of the preceding day. (U. S. Weather Bureau.)

Cold waves often attend the anticyclones. These winds are known as *northers* in the southern part of the United States, and sometimes as *blizzards* in the northern part, though this name usually implies heavy snowfall and high wind, as well as low temperature. Fig. 414 shows the weather map for January 3, 1896, and Fig. 415 the map for the following day. The high of Montana has advanced to Arkansas and Mississippi, and a freezing temperature has been carried down to the orange groves of northern Florida.

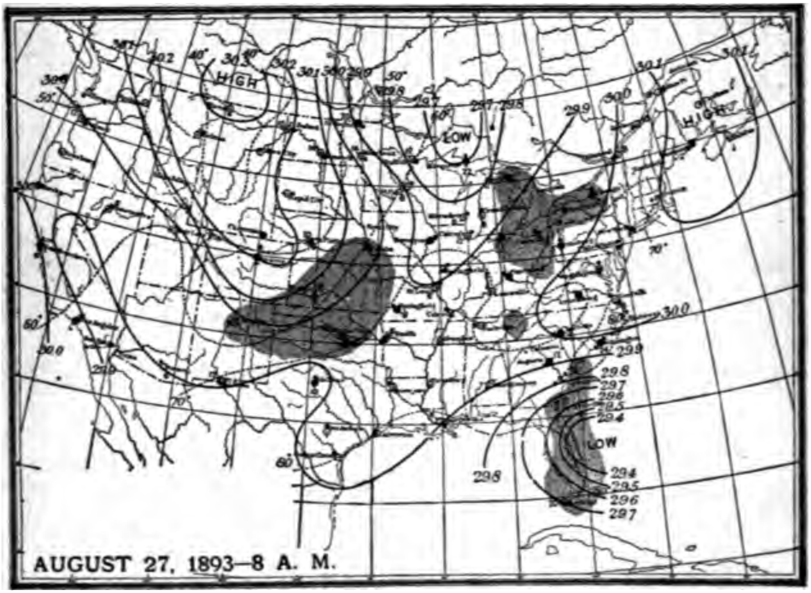


Fig. 416.—Weather map showing a tropical cyclone, central off Florida. (U. S. Weather Bureau.)

The *mistral* and the *bora* of southern Europe belong to the same class as the northers of our country.

Origin of the cyclones and anticyclones. The origin of cyclones and anticyclones of middle latitudes is not well understood. The movements of air in a cyclone are about what they would be if the cyclone were due to convection, and there is no doubt but that centers of low pressure might be brought about by the excessive heating of areas; but this can hardly be the origin of the cyclones of these latitudes, for they are about as common in winter as in summer, and in the winter season they often originate in areas covered with snow, where excessive heating is impossible. Similarly, anticyclones might be conceived to result from the unusual cooling of certain areas; but that this is not their cause seems clear, because (1) they sometimes originate in warm regions, and (2) they are scarcely more abundant in cold weather than in warm weather.

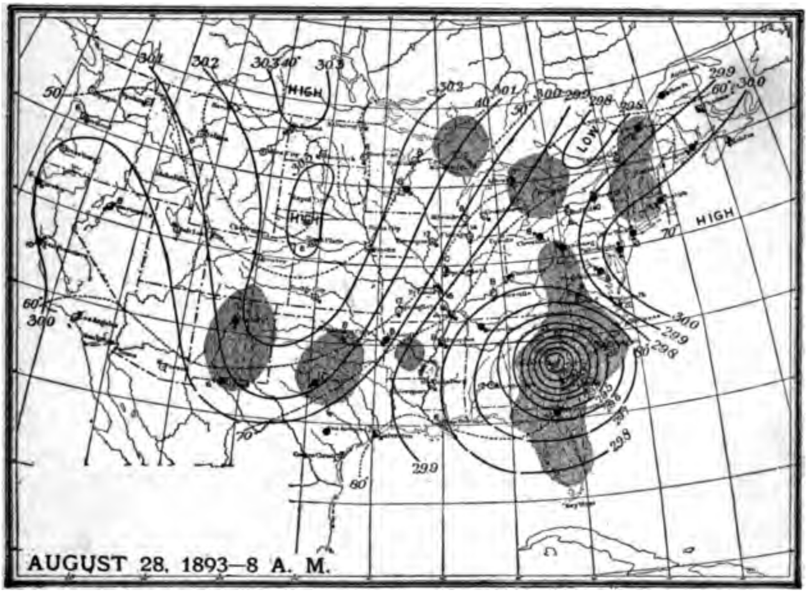


Fig. 417.—Weather map showing the progress of the storm shown in Fig. 416. (U. S. Weather Bureau.)

The origin of cyclones and anticyclones is probably not to be explained by temperature at the bottom of the atmosphere. It is probable that both are special phases of the general circulation already outlined. We may leave the subject here with the statement that no detailed explanation of cyclones and anticyclones has yet been generally accepted.

Tropical cyclones. Cyclones sometimes start in tropical regions, and follow courses very different from those of the cyclones of middle latitudes. The cyclones of this class which reach North America usually originate in the West Indies, and are most common in the late summer and early autumn. They follow a northwesterly course until the latitude of Florida is reached. Here they commonly turn to the northward, and later to the northeastward, following the Atlantic coast. Figs. 416–419 show the course of one of these storms in August (27–30), 1893, and Fig. 420 shows the average path of the tropical cyclones for the months of August, September, and October, for the years 1878 to 1900.

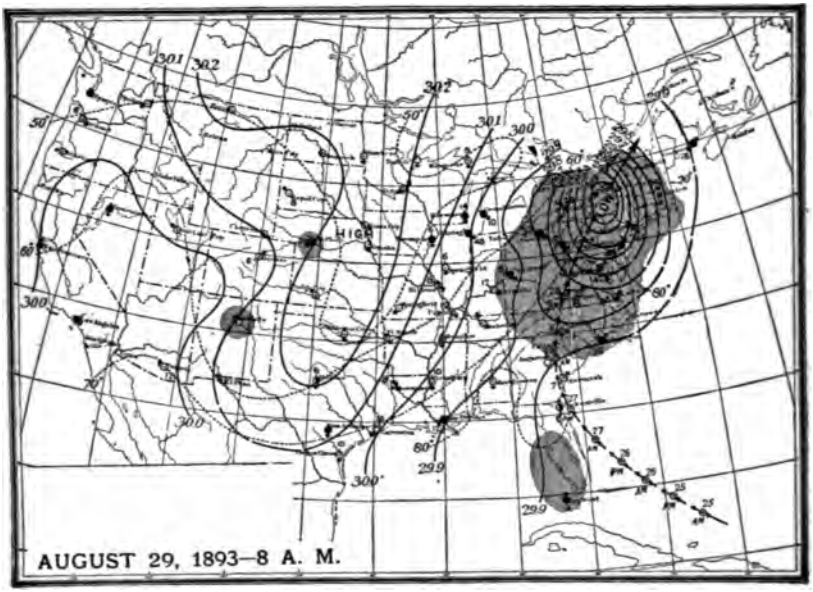


Fig. 418.—Weather map showing further progress of the storm shown in Figs. 416 and 417. (U. S. Weather Bureau.)

The tropical cyclones are usually stronger than those of intermediate latitudes; that is, the gradient and the winds are higher. They often do great damage along the coast, both to shipping and to the low lands near the water. The storm which worked such disaster to Galveston in September, 1900, is shown in Fig. 421. This figure also shows (1) the course of the storm before it reached Galveston and after leaving it, and (2) the rate of its progress. The strength of the storm was exceptional, and its course unusual, as will be seen by comparing Fig. 421 with Fig. 420. The rate of progress of the storm was very unequal. Thus northwest of Cuba its progress was much slower than it had been to the southeast.

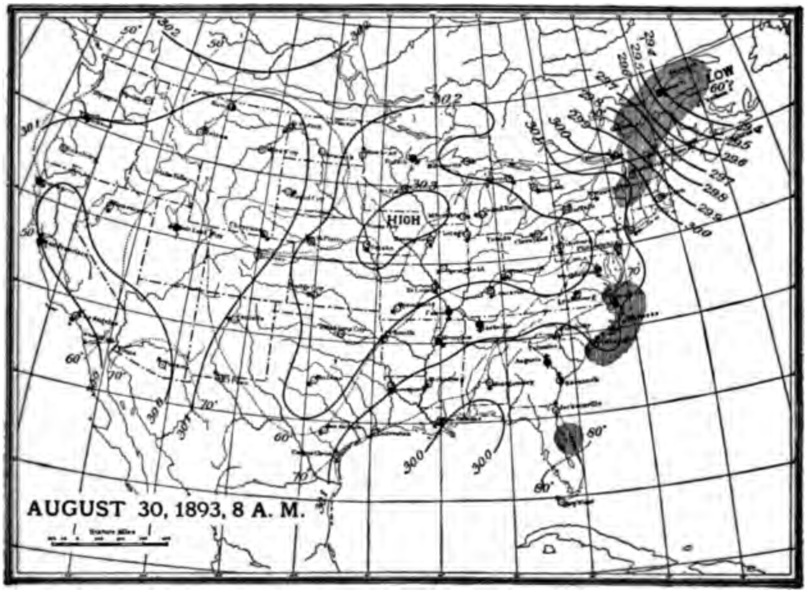


Fig. 419.—Weather map showing the last of the storm shown in the preceding figures. (U. S. Weather Bureau.)

Tropical cyclones do not occur in the South Atlantic, but in the Pacific they occur on both sides of the equator. They occur in the later part of the hot season of the latitudes where they occur.

Tropical cyclones are thought to be caused by strong convection currents. Their courses are probably to be explained by the courses of the prevailing winds. The lower part of the tropical cyclone, in its early history, is in the horizon (p. 389) of the trades, but the upper part of the great eddy is probably above the trade-winds, and under the influence of winds blowing to northward (northeastward). The effect of these two sets of winds appears to be to carry the storm somewhat to the north of west until it gets out of the trade zone. It is then directed chiefly by the southwest winds.

The tropical cyclones of the North Pacific start in the vicinity of the Philippines, and sweep the coast of China. They are called *typhoons*, and their courses are shown in Fig. 422. The Society Islands and the low coral islands of the neighboring low archipelago were swept by a destructive storm of this sort on February 7 and 8, 1906.

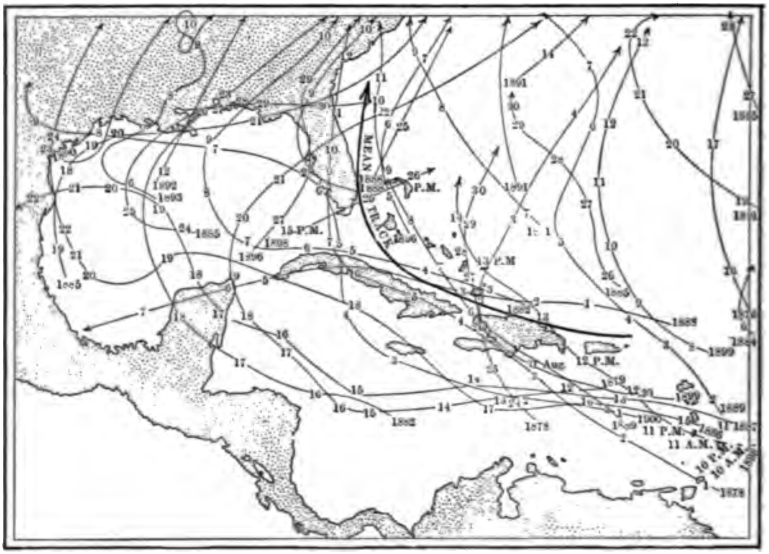


Fig. 420.—Course of West Indian storms for August, September, and October, 1878–1900. The lighter lines show the tracks of individual storms, the heavy line the mean course. (U. S. Weather Bureau.)

Weather predictions. Weather predictions are based on the facts shown on weather maps. Take, for example, the map of the 25th of September, 1903 (Fig. 407). Rain accompanies the cyclone which is central over Dakota. Since this storm has, for the last 24 hours, been moving a little south of east at the rate of about

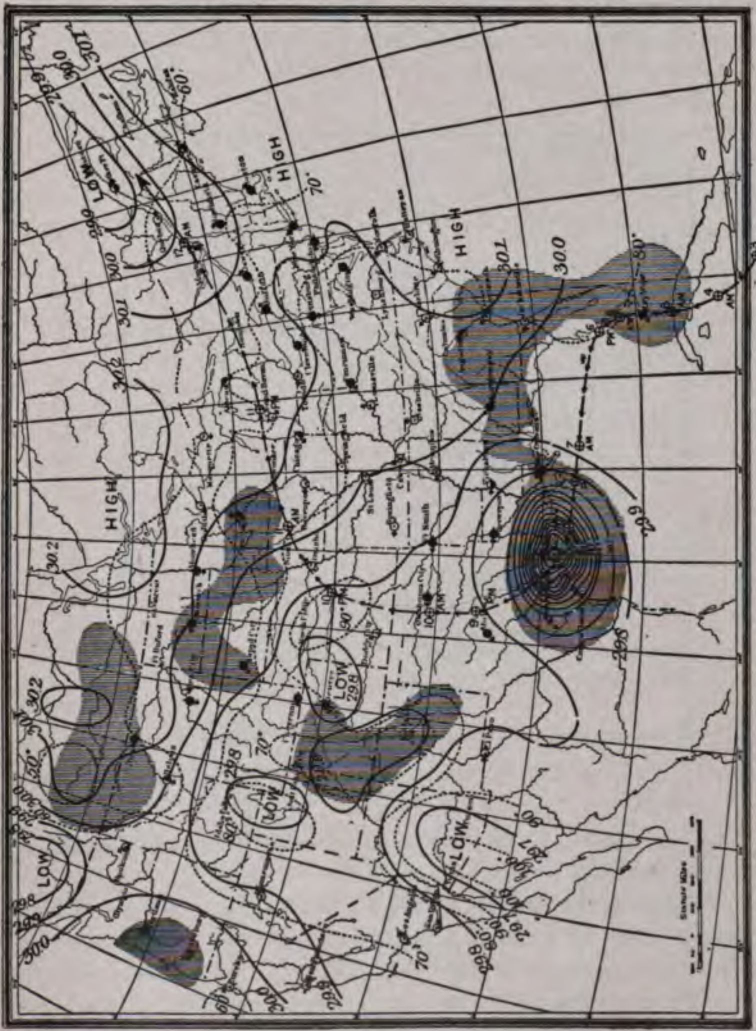


Fig. 421.—The Galveston storm of September 8, 1900. The line of arrows extending from Galveston (through Kansas, Michigan, etc.) to Maine shows the later course of the storm. (U. S. Weather Bureau.)

40 miles an hour, it is fair to presume that it will move in this same general direction at a similar rate for the next 24 hours. If, in this time, it advances to the Lake Superior region, it will probably bring with it weather similar to that which it is now giving to the region where it occurs. Hence, on the 25th, the prediction might be made that rain is to be expected in about 24 hours in the region about the head of Lake Superior.

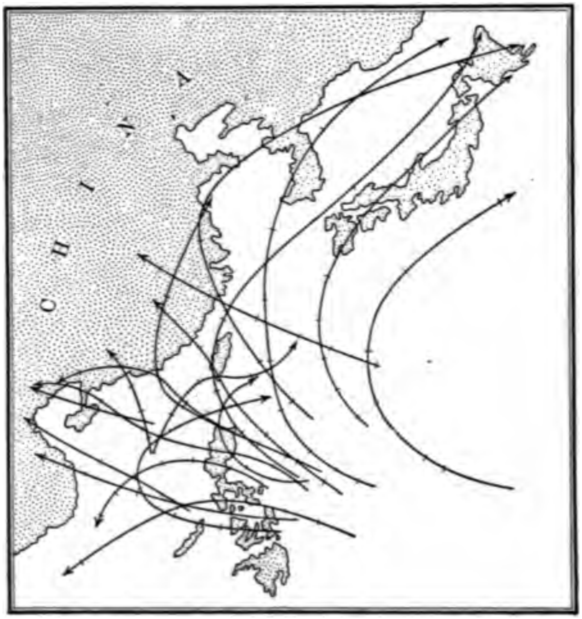


Fig. 422.—Typhoon tracks. (Herbertson.)

On the 26th the prediction might be made that the low which is central north of Lake Superior (Fig. 408) will move on to the Gulf of St. Lawrence by the succeeding day, and that rain will accompany it. Rain for the region about Lake Huron and the area east of it may, therefore, be predicted for the 27th. The chart for that day (Fig. 409) shows that the area of precipitation extends far to the south. The preceding map had shown some cloudiness in this region, but had afforded no warrant for the prediction of such an area of precipitation as appears on the map of the 27th.

Temperature changes as well as changes in precipitation may be predicted. Thus in Fig. 406 the isotherm of 40° bends southward notably in the high central over Iowa. As the high moves east, it will probably carry the low temperature with it. Hence it is safe to predict that the temperature will fall in the area into which the anticyclone is to move. The map of the succeeding day (Fig. 407) shows that the temperature of western Virginia has fallen from about 60° to about 40° along the path of the high, while areas much farther north are warmer.

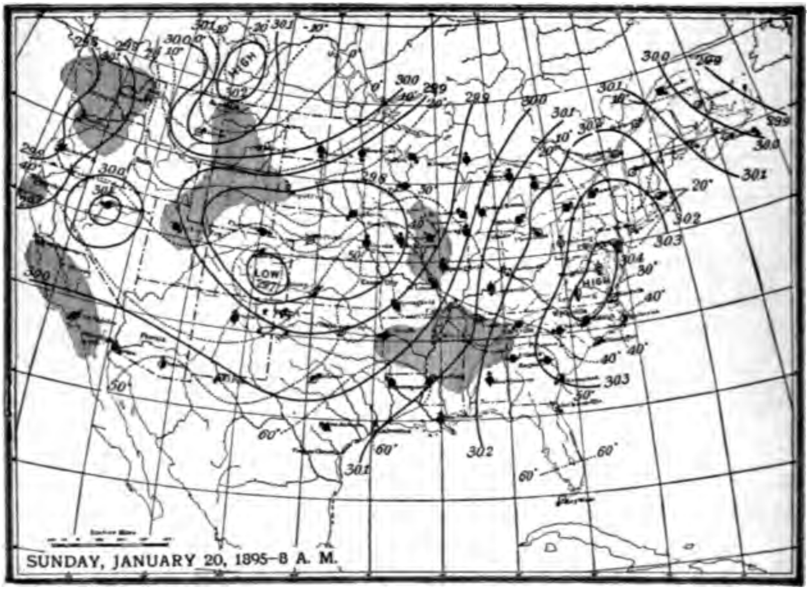
Fig. 407 also shows that North Dakota and Alberta have a temperature of 50°, that is, a temperature 10° warmer than that of western Virginia. It will be noted, too, that the relatively high temperature of Dakota, Montana, and Alberta goes with a low. As the cyclone moves eastward, the temperature along its path will probably rise. This is shown by the map of the next day (Fig. 408), which shows a temperature of about 50° north of Lake Superior. The same map shows how the isotherm of 40° bends to the southward in front of the high which is central over western Montana. As the high of Montana moves eastward, it will be likely to carry cold temperature with it. From this map, therefore, it may be predicted that the temperature in Nebraska, Kansas, Iowa, and Missouri will fall.

The time when the rain which a given storm may bring to any given place will fall is calculated from the rate at which the storm is progressing, and the prediction of the time of arrival of a cold wave which an anticyclone is likely to bring, is based on the rate of progress which the anticyclone is making. This rate is known in advance for each anticyclone by telegraphic reports. Predictions concerning the weather may be made more readily for the central and eastern parts of the United States than for the western part, for the storms have been under observation longer before they reach the central and eastern parts.

Predictions may also be made as to the strength and direction of wind.

Failure of weather predictions. Weather predictions often fail. The reasons are many. Some of them are the following:

1. Cyclones and anticyclones sometimes depart widely from the courses they are expected to take. Thus a storm may be in line for St. Paul, to which it is expected to bring rain and a rising temperature; but instead of keeping its course, it may turn off to the northward, and the rain which was predicted for that city, falls farther north.



SUNDAY, JANUARY 20, 1895—8 A. M.

Fig. 423.—(U. S. Weather Bureau.)

2. Storms often change their rate of advance, and so arrive earlier or later than predicted. The high of Oregon (Fig. 406) did not advance for a day (Fig. 407), and so failed to bring the expected changes to the area east of it.

3. A third cause of the failure of predictions is found in the fact that storms sometimes appear and disappear without warning. Fig. 408 shows a low of which there had been no indication

on the 25th, over Oklahoma. Fig. 409 shows that this low has disappeared.

4. A storm sometimes changes its character, becoming weaker or stronger, etc. Figs. 423 and 424 afford an illustration. Nothing in the map of the 20th would warrant the prediction of the conditions of weather shown on the map of the 21st.

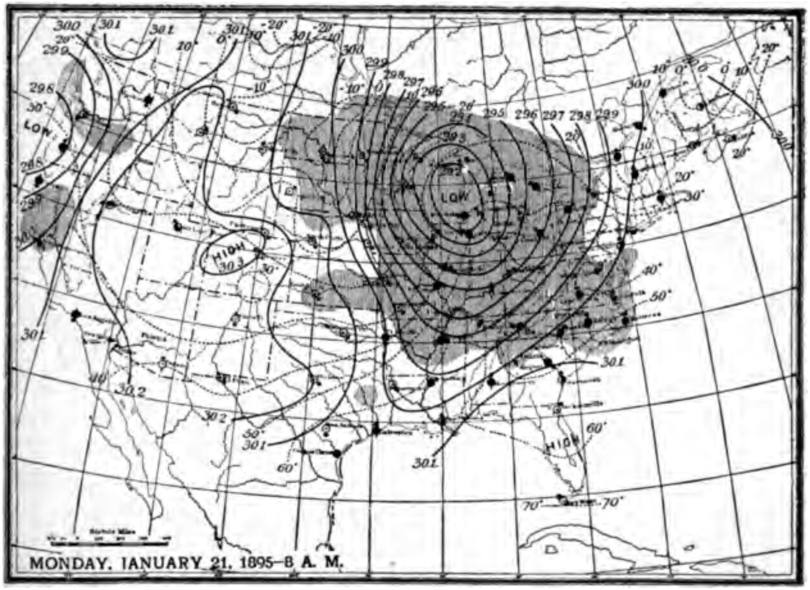


Fig. 424.—This map shows the storm of the preceding day greatly changed in character. (U. S. Weather Bureau.)

5. Predictions are sometimes based on imperfect data. On some weather maps the letter *M* appears in various places. This means that reports from the station where the *M* appears are missing. If many reports are missing, the map is imperfect, but the forecaster must use such data as he has, as well as he may, and issue a map.

6. In some situations storms are subject to many freaks. This is the case, for example, at Chicago, where the lake modifies temperature and air currents.

Forecasters, like other men, make mistakes, but when they have to work with so many uncertain elements, it is not strange that their predictions are sometimes wrong, and one mistake is likely to be remembered longer than many correct forecasts.

Property saved by predictions of storms, frosts, floods, etc. In spite of all mistakes, the warnings of storms, floods, cold waves, etc., sent out by the Weather Bureau, have been of great benefit. The value of this service is not always duly appreciated, and much less is heard of it than would have been heard of the losses which would have resulted if warnings had not been given. Unfortunately, it is not always possible to devise protection against the evils of which the Weather Bureau gives warning.

It has been estimated that property valued at $15,000,000 was saved in 1897 by warnings of impending floods. In 1903–4 the estimated saving was $1,000,000.

Shipping interests are served by warnings of storms. Thus, in September, 1903, vessels valued at $585,000 were held in ports temporarily, along the coast of Florida, by storm warnings.

Agricultural interests are also served by warnings of storms and of "cold waves," and especially of frosts. Warnings led to the protection of $1,000,000 worth of fruit about Jacksonville, Florida, in 1901, with an estimated saving of half this amount. Other warnings of cold in 1901 were estimated to have been the means of saving more than $3,000,000 worth of property. Fruit and truck farming are the phases of agricultural work most effectively served in this way.

Special Types of Storms

Thunder-storms. Thunder-storms are frequent in the United States. They are most common in warm regions, and in warm seasons. Further, they are most common on days which are unusually warm, and during the warmer parts of these days; but there are occasional thunder-storms in the winter, and there are thunder-storms at night.

The first indication of a thunder-storm is usually a large cumulus cloud (Fig. 425) which, in the zone of the westerly winds, generally appears in the west. It moves eastward, and as it reaches the place of the observer, there is usually a smart breeze, or *thunder-squall*, rushing out before it. Shortly after the squall the rain begins to fall. The rainfall is often heavy, and the drops large; but the downpour does not usually last more than an hour, and often much less. A second thunder-storm sometimes follows close upon the first, thus prolonging the period of rainfall. When a thunder-storm has moved on to the east, the air is notably cooler and fresher, and the barometer distinctly higher.

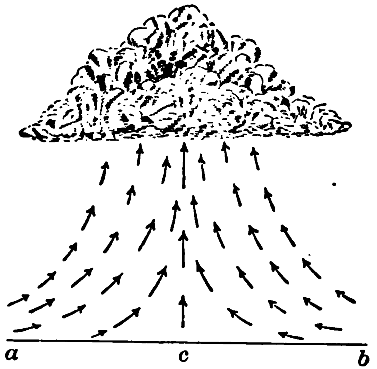


Fig. 425.—Ascending currents and cumulus cloud before a thunder-storm. (Ferrel.)

When water is condensed rapidly in the air, electricity is produced, and the surface of each water particle becomes charged with electricity. The charge of the individual droplets increases as they increase in size, and the lightning is due to the discharge of the electricity from one part of a cloud to another, or from one cloud to another, or from the cloud to the ground.

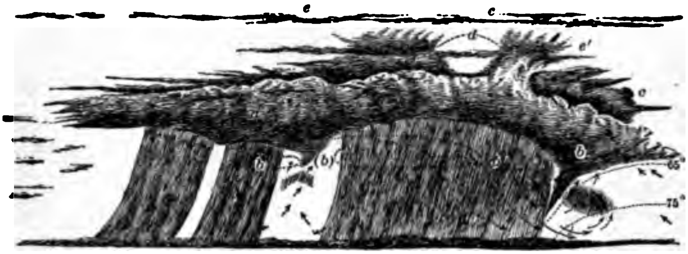


Fig. 426.—Vertical section of a thunder-storm which is moving toward the right. (Köppen.)

The flash of lightning is followed by thunder, the noise being due to the vibrations in the air caused by the electrical discharge. The thunder has been compared to the noise which follows the explosion of a rocket or the cracking of a whip (Davis).

In middle latitudes, thunder-storms usually occur during the passage of cyclones, though they do not accompany all cyclones. They are more common on the south sides of cyclones than elsewhere, and they often occur at a considerable distance from the center of the storm. In middle latitudes, thunder-storms move generally from west to east, while in the zone of trade-winds they move from east to west. In both cases they move with the prevailing winds.

The forward movement of thunder-storms is commonly 20 to 50 miles an hour. They often spread, and become weaker as they move forward (Fig. 427). They usually disappear before they have traveled far. The period of a thunder-storm is usually much shorter than that of the cyclone which it accompanies.

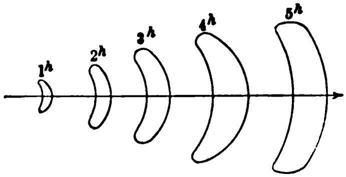


Fig. 427.—Shape of thunder-storm in ground-plan, illustrating its growth and change as it progresses. (Waldo.)

It sometimes happens that lightning at a great distance lights the clouds over a region where the electric discharge itself cannot be seen. This lighting of the clouds is often called *heat lightning*, because it is more commonly seen in hot weather than at other times.

Rainbows sometimes accompany or follow thunder-storms. They are usually seen just after the passage of a thunder-storm, while a little rain is still falling, but after the sun has appeared. They are seen opposite the sun, that is, in the west in the morning, and in the east in the evening. There is sometimes a second bow outside the first, but fainter. The rainbow is due to the effects of the drops of water in the atmosphere on the sun's rays. A bow is also seen when water spray, such as that at a great waterfall, is seen in the bright sunlight.

Whirlwinds. Distinct ascending whirls of air are often seen on hot days. They are most distinct in dusty regions, for there the dust which is swept up makes the whirl conspicuous. From a given point in the Mojave Desert, in California, as many as eight or ten of these whirls, some of them rather large, have been seen at one time on a hot summer day. The whirlwinds are probably caused by the excessive heating of the air at some point, and this excessive heating gives rise to a sharp convection current. It moves on for a time with the prevailing wind, but soon plays out.

In humid regions the whirlwinds do not usually appear to extend up to any considerable height; but in desert regions they often reach heights of 1,000 feet or more, as shown by the whirling columns of dust. The rise is sometimes so great that the air is expanded and cooled enough to cause condensation of even the small amount of moisture contained in the desert air. Smart showers may then occur. Showers of this sort are likely to be of short duration, but the rainfall is sometimes very heavy. If exceptionally heavy, such rains are known as *cloudbursts.* In such a storm in the summer of 1898, rain enough fell in a few minutes, in the vicinity of Bagdad, in the Mojave Desert of California, to occasion serious washouts along the railroad for miles. A cloudburst at Clifton, S. C., June 6, 1903, caused the loss of more than 50 lives, and property damage to the estimated extent of $3,500,000. In desert regions the water which starts to fall from the rising and expanding air is sometimes evaporated before it reaches the ground. Such "suspended" showers may often be seen in Arizona in August.

Tornadoes. When a convection current is very strong, and has very small diameter, the whirl sometimes becomes so intense as to cause great destruction. A whirling storm of this sort is a *tornado.* Tornadoes, like thunder-storms and whirlwinds, are phenomena of hot weather. They occur in the United States in the warm season, appearing earlier in the south, and later in the north. They are rather less abundant in the later part of the summer than in the earlier part. They are more likely to occur in a cyclone than in an anticyclone.

The tornado may be looked upon as a concentrated cyclone or strong whirlwind. The atmospheric pressure in the center of the tornado is usually much lower than in the center of a cyclone. In a very strong tornado the pressure at the center may be a fourth less than that of its surroundings. This is one reason why the tornado is so destructive. During its passage the pressure may be reduced from the normal amount, 14.7 lbs. per square inch, or 2,117 lbs. per square foot, to three-fourths of this, or to 11 lbs. per square inch, or 1,584 lbs. per square foot. If such a tornado passes over a closed building in which the air pressure is 2,117 lbs. per square foot, the pressure on the outside becomes 1,584 lbs. The walls are therefore pushed out with a force of 533 lbs. per square foot, and unless they are very strong, they will fall, as if the building had exploded. Sometimes only the weakest part, such as windows, yields.

Not only is the pressure at the center of the tornado low, but the area of low pressure is very small. While a cyclone may be 1,000 miles or more across, a tornado may be no more than one-eighth of a mile across, or even less. The result is that the pressure gradient in a tornado is very much higher than in a cyclone, and the winds are violent. Their velocities, estimated by the size and height of the objects moved, have been thought to reach 400 or 500 miles per hour. With this velocity, or even a velocity which is much less, the destruction is great. Trees are overturned, buildings unroofed or even blown down, and bridges hurled from their foundations.

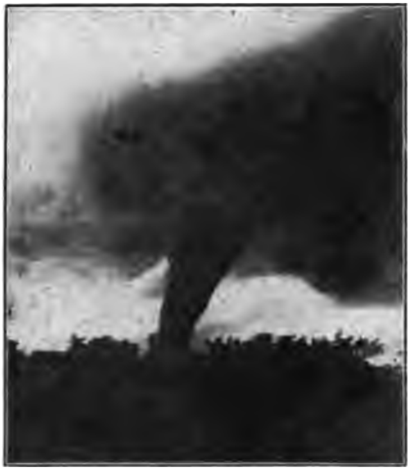


Fig 428.—Funnel-shaped cloud of a tornado. Solomon, Kan. (U. S. Weather Bureau.)

A tornado is often seen first as a funnel-shaped cloud (Fig. 428), the point of which may be far above the ground. As the funnel moves forward, its lower end may rise or fall. The cloud is due to the condensation of the moisture in the sharp convection current, and the funnel shape is due to the expanding and spreading of the air as it rises.

The tornado is, of all storms, the most destructive, but it usually has a very narrow track, and does not usually work destruction for a very great distance. After a short course it usually plays out, or rises above the land.

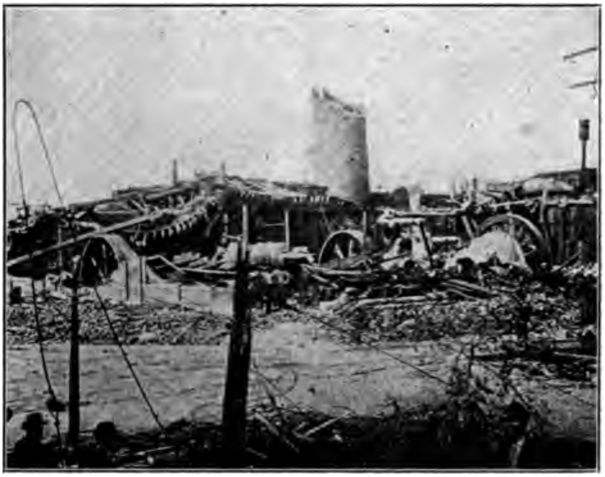


Fig. 429.—Wreckage of the Union Station Power-house at St. Louis, May 27, 1896. (U. S. Weather Bureau.)

One of the most destructive, though not one of the most violent, tornadoes of recent times was that at St. Louis, May 27, 1896. It accompanied a thunder-storm in the southeastern part of a cyclone central some distance northwest of St. Louis.

The relative humidity at St. Louis was exceptionally high, about 94. At noon the barometer stood at 29.87, the temperature was 80° F. and the velocity of the wind 12 miles per hour. By 1:45 the temperature had risen to 86°. At 2 o'clock the barometer began to fall rapidly, and by 6 P. M. it had dropped to 29.59.

Shortly before 6 o'clock the wind had attained a velocity of 45 miles per hour, and by 6 o'clock the temperature had fallen to 77°.

The cumulus clouds which had formed during the early part of the afternoon had settled into a stratus cloud by 4:30. Soon after 5 o'clock, thunder and lightning occurred, and rain began to fall at 5:43.

At 6:04 there was a marked increase in the violence of the wind, which shifted its direction frequently. The barometer rose to 29.67, but fell almost instantly to 29.57, then rose to 29.67 in less than 5 minutes, falling again .31 inches to 29.36 in 15 minutes, and then rose almost instantly to 29.76. Sharp oscillations of barometric pressure occurred until 10 P. M. The wind probably attained a maximum velocity of 120 miles per hour at 6:18, with numerous and rapid changes in velocity and direction. The rainfall accompanying the storm was extremely severe, more than $2\frac{1}{2}$ inches falling. The electrical display was brilliant.

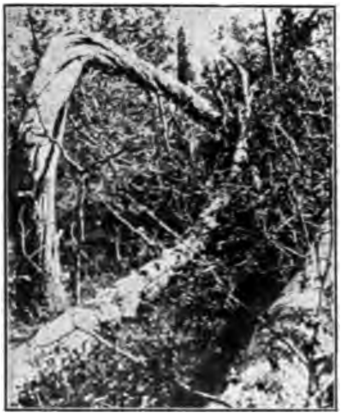


Fig. 430.

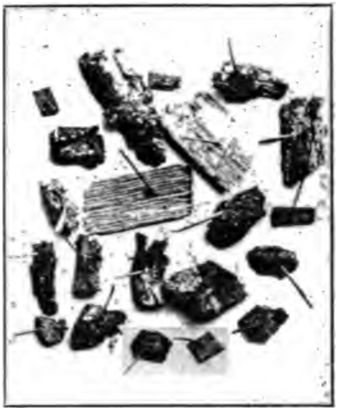


Fig. 431.

Fig. 430.—Trees twisted off by tornadic winds. (U. S. Weather Bureau.)
Fig. 431.—Straws driven into dry wood by tornadic winds. (U. S. Weather Bureau.)

The destruction began at about 6:10 P. M. and lasted for several minutes. The forward motion of the storm was at the rate of about 36 miles per hour. The width of the belt of destruction was about 1¼ miles where it entered the city, but it was narrowed to less than a mile farther on.

One of the extraordinary features of the storm was the fact that its base was about 30 feet above the surface. Trees were twisted off at this level, and the principal destruction of houses was above the first floor.

As in other tornadoes, the wind played many curious freaks. Single stones and bricks were picked out of walls, while the walls remained standing. In one case a span of horses attached to a loaded wagon were blown away, though the wagon was not overturned. The most extraordinary recorded instance of violence was in East St. Louis, where, at the approach to the bridge, a plank 2″ × 8″ "was driven into . . . a steel girder with such force that it punched a hole in the webbing and remained sticking in the girder." The destruction of property in and about St. Louis was estimated at about $13,000,000.

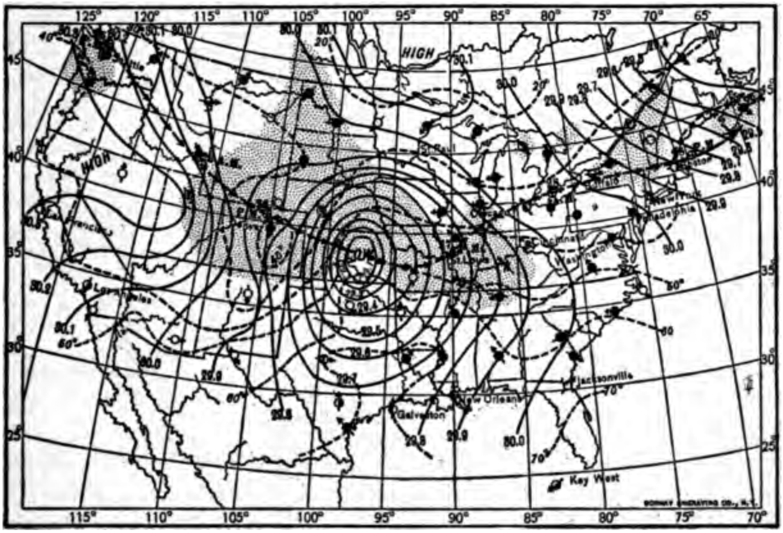


Fig. 432.—Weather map for the morning of the day (March 27, 1890) of the Louisville tornado. (U. S. Weather Bureau.)

A more violent tornado was that at Louisville on the 27th of

March, 1890, just before nine o'clock in the evening. Its rate of advance was nearly 40 miles per hour, but its diameter was so slight, about 300 yards, that it took but about three-fourths of a minute for the storm to pass a point. It was accompanied by "a most terrific electric display." Many weak buildings were wrecked, 76 persons were killed and about 200 injured in Louisville alone, and the loss of property was estimated at about $2.500.000.

The path of the storm was traced for 75 miles, and throughout this distance its width was nearly uniform. At least five tornadoes occurred in Kentucky the same night.

Waterspouts. Waterspouts are tornadoes at sea. When the base of the upward spiral movement is down to the surface of the water, sea-water may be drawn up to some slight extent by the ascending current. The lesser atmospheric pressure in the center of the whirl will occasion the rise of the water to some extent at that point, and the upward current of air may catch it and carry it upward. But the larger part of the water in a waterspout is probably cloud, formed by the condensation of the water vapor in the air, and not by the uplift of water from the sea.

Foehn winds, chinook winds, etc. When warm, moist air is forced up over mountains, it precipitates some of its moisture. The precipitation sets free heat, so that the air is cooled much less than it would be otherwise. Beyond the crest of the mountains it descends, and is warmed in the process. It is warmed much more (often twice as much) in the descent than it was cooled in the ascent. It may, therefore, descend as a hot wind. Such winds are known as *foehn* winds in Switzerland, and as *chinook* winds in the United States, especially just east of the Rockies. The same process takes place in other regions.

These winds may be beneficial or harmful. Thus the chinook winds temper the rigorous winters of certain parts of the northwestern states and the Canadian provinces east of the mountains. They frequently evaporate a foot or more of snow in a few hours. For this reason they are sometimes called *snow-eaters.* These winds make winter grazing possible over large areas. In the province of Alberta the chinook has been declared to be "the grand characteristic of the climate as a whole, that on which the weather hinges." These winds sometimes develop with great suddenness. At Fort Assiniboine, Montana, on January 19, 1892, the temperature rose 43° F. (from −5.5° to 37.5°), in fifteen minutes, under the influence of the chinook wind. In other cases the temperature has been known to rise 80° in six or eight hours.

The chinook winds of summer are sometimes so hot and drying as to wither vegetation, and occasionally to destroy crops completely.

CHAPTER XVIII

CLIMATE

Something has been said concerning climate in preceding chapters, but the subject will be summarized here, and studied in connection with the zones of the earth.

Definition. Climate is the average succession of weather conditions for a long period of time. The average weather of a place for ten years would give some idea of its climate; but the average weather for twenty years would be better, and the average for 50 or 100 years would be better still. The distinction between climate and weather is correctly recognized by such expressions as these: The winter climate of Chicago is cold and windy; but the winter weather of Chicago in 1905-6 was mild.

The Elements of Climate

The principal elements of climate are temperature, moisture, and wind. Of these, temperature is, on the whole, the most important, but from some points of view, humidity is of almost equal significance.

Temperature as an element of climate. In speaking of the climate of a region, account is taken not only of (1) the average temperature of the year and (2) the average temperature of the several seasons, but also of (3) the temperature of exceptional seasons, and (4) the extremes of temperature during the season. *Sensible temperature*, or the temperature as it *feels* to us, and *absolute temperature*, as shown by a thermometer, are also to be taken into account. Moist air of a given temperature seems much warmer than dry air of the same temperature when the temperature is high, and much colder when the temperature is low. Sunstroke is much more common where the relative humidity is high than where it is low. Sunstrokes are rare, for example, in the arid west, even with temperatures much above those of Chicago or New York. Sudden changes of temperature are also less harmful where the relative humidity is low than where it is high. Air of a given temperature seems cooler when in motion than when quiet.

Moisture as an element of climate. Climate takes account of (1) the average amount of yearly precipitation, (2) the variations of precipitation from year to year and from season to season, (3) its average distribution through the year and departures from this average, (4) the proportions which fall as rain and snow respectively, (5) relative and (6) absolute humidity even when there is no precipitation, and (7) cloudiness.

Uniform and variable climate. If the range of temperature is small, the distribution of precipitation somewhat equal, the winds nearly constant in direction and strength, the climate is *uniform.* If, on the other hand, the variations of these climatic elements are great, either in one year or in successive years, the climate is *variable.* The climate of the middle and northern latitudes of the United States is variable because (1) the annual range of temperature is great, (2) because the range varies from year to year, (3) because two summers or two winters may have very different temperatures, (4) because changes of temperature may be very sudden, and (5) because the amount and distribution of rainfall and snowfall vary much from year to year, and from season to season.

Figs. 433–438 show certain elements of variability. Fig. 433 shows the annual range of temperature in four places. Reading from the top down, these are Duluth, Chicago, Memphis, and New Orleans. In the thirty years represented in the figure, the least range in one year at Duluth was a little less than 110°, and the greatest 135°, with an average of 120°; at Chicago the least range in these years was 95°, and the greatest nearly 120°, with an average of 108°; at Memphis the range in a year was from 75° to 105°, with an average of 87°; while at New Orleans the range in a year varied from 60° to 90°, with an average of 70°. The range in the year is greater in the higher latitudes, and less in the lower.

Fig. 434 shows the ranges each year for thirty years for Denver, Chicago, New York, and San Francisco. The ranges for the first three do not differ much, but the range at San Francisco, where the prevailing wind is from the sea, is much less. Although equally near the sea, New York has a much greater range of temperature than San Francisco, because the prevailing winds in the former place are from the land, while those of the latter are from the sea.

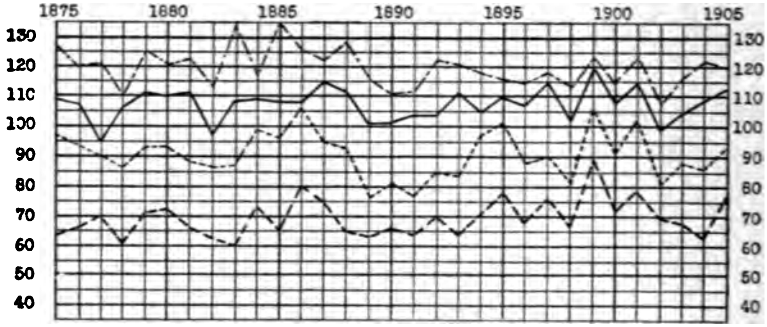


Fig. 433.—Reading from the top down, this figure shows the annual range of temperature in degrees Fahrenheit at Duluth (average range 120°), Chicago (average range 108°), Memphis (average range 87°), and New Orleans (average range 70°). These four places are in about the same longitude, but in different latitudes.

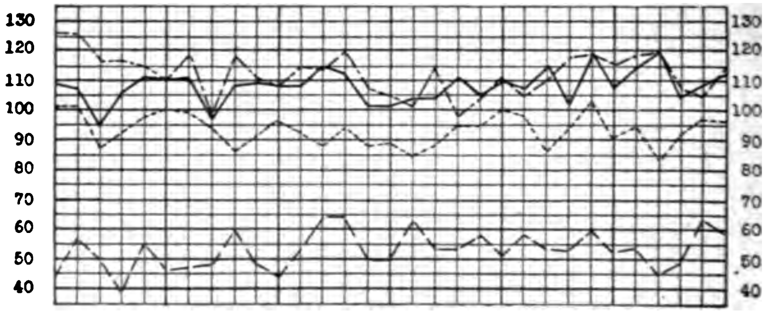


Fig. 434.—Reading from the top down, this figure shows the annual range of temperature in Denver (average range 113°), Chicago, New York (average range 94°), and San Francisco (average range 53°), four places in similar latitudes, but in different positions with reference to the sea.

Fig. 435 shows the average winter temperatures for ten years at Chicago. It will be seen that the average temperature of the winter of 1889–90 was more than 6° higher than that of some others. Fig. 436 shows the mean monthly temperatures for four cities. The letters at the top of the figure stand for the months, and the numbers at the left are degrees Fahr. The range of temperature is greater the higher the latitude, and the greater the distance from the sea in the direction from which the wind blows.

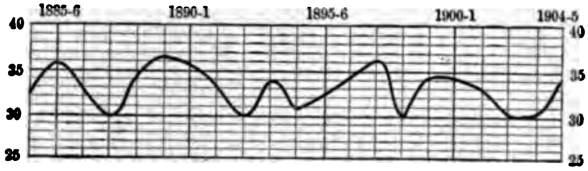


Fig. 435.—Average winter temperatures at Chicago in degrees Fahrenheit, 1885–1905. (Cox, U. S. Weather Bureau.)

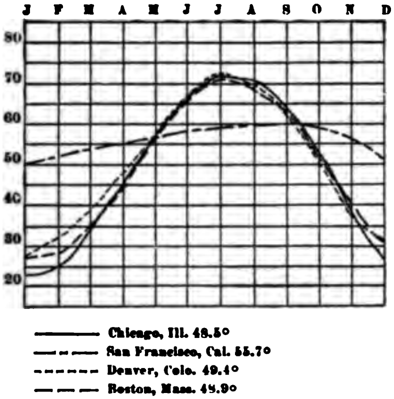


Fig. 436.

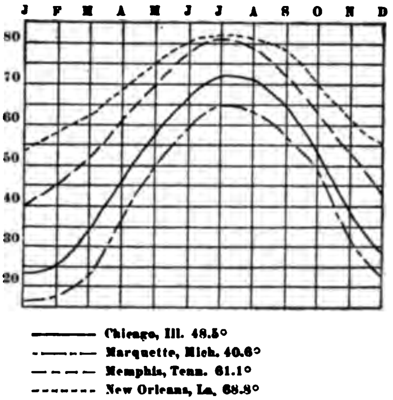


Fig. 437.

Fig. 436.—Mean monthly temperatures in degrees Fahrenheit at Chicago, San Francisco, Denver, and Boston, four places in similar latitudes. (U. S. Weather Bureau.)

Fig. 437.—Mean monthly temperatures in degrees Fahrenheit at Chicago, Marquette, Memphis, and New Orleans, places in different latitudes in about the same longitude. Averages for the year are also shown below the graphs. (Cox, U. S. Weather Bureau.)

Fig. 437 shows the variations in temperature in four places in about the same longitude, but in different latitudes, the range being least in the lowest latitude. Fig. 438 shows the variation in snowfall in one locality for a period of 20 years.

A variable climate varies in different ways. A region which is always dry during one season of the year and wet during another has a climate which is *variable within the year with reference to precipitation;* the climate of such a region may, however, be very nearly the same from year to year. Such a climate is found in some places on the borders of the equatorial calms, which shift a little north and south with the apparent shifting of the sun. The land near the borders of this zone are sometimes in the calms and sometimes outside them. At the former times they have more rain, and at the latter less.

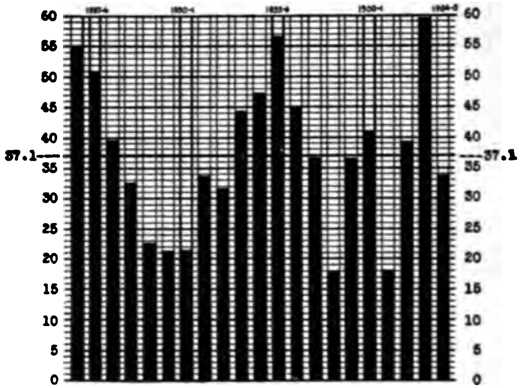


Fig. 438.—Total snowfall at Chicago, in inches, by winters, 1885–1905, showing the great variations. The numbers at the sides represent inches. The average for the 10 years is 37.1 inches, while the extreme range is from 18 to 59. (Cox, U. S. Weather Bureau.)

A region which is hot at one time of the year and cold at another is *variable within the year with respect to temperature.* In such regions, too, one winter or summer may be much cooler or warmer than the next, giving a variation from year to year rather than from season to season. A climate which is variable with respect to temperature is not necessarily variable with respect to moisture. Commonly, however, variations in temperature and moisture go together.

In some regions the winds shift regularly from season to season, as where monsoons blow. The climates of such places are *variable* *within the year with respect to winds,* and this makes them variable also with respect to other elements of climate. The climates of such regions may be uniform from year to year.

The climate of a region may vary in other ways also. Thus some summers or some winters may be much warmer or much drier than others. The meaning of "variable climate" is therefore itself variable.

Classification of Climates

As in the case of many other topics, climates may be classified in various ways, and each classification helps to emphasize some important point. One classification has already been suggested, namely, *uniform* and *variable.*

Another classification has reference primarily to the *amount of heat received from the sun.* On this basis the earth is subdivided into climatic zones, the borders of which are parallels. These climatic zones may be said to represent *solar climate,* but the climate which insolation alone would give is much modified by other factors, as we have seen.

The effect of land and water on temperature has already been noted. It is so important that climates are also classified as *oceanic* and *continental.* Continental climates, in turn, may be subdivided on the basis of (1) distance from the sea, (2) height above the sea, and (3) topographic relations. The controlling element in most of these classifications is temperature.

Climatic Zones

The climatic zones commonly recognized are (1) the *torrid zone,* the center of which is the equator, (2) the *temperate zones,* which occupy the extra-tropical latitudes, and (3) the *frigid zones,* which lie about the poles. Better names for these zones are the *tropical,* the *intermediate,* and the *polar* zones[1] respectively, and these terms will be used hereafter. The limits of these zones have been variously defined. One classification defines them by *latitude,* a second by the direction of the *winds,* and a third by *temperature.*

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[1] Ward, Bull. Am. Geog. Soc., vol. xxxviii. 1900.

Zones defined by latitude. Defined by latitude, the tropical (or torrid) zone lies between the tropics (23½° N. to 23½° S.), the two polar zones extend from the poles to the Arctic and Antarctic circles respectively (90° N. to 66½° N., and 90°S. to 66½° S.), and the two intermediate zones lie between the tropical zone and the polar zones on either hand (23½° N. to 66½° N., and 23½° S. to 66½° S.). The zones defined by latitude are shown in Fig. 439.

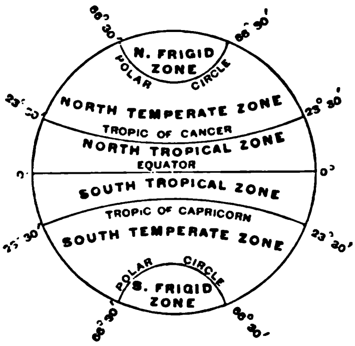

Fig. 439.—Diagram showing the zones, as defined by latitude.

According to this classification, the *tropical zone* is the zone (1) where the sun is vertical at some time during the year, (2) where variations in the length of day and night are least, (3) where the annual insolation is greatest, (4) where the range of annual insolation is least, and consequently (5) where the annual range of temperature is least.

The *intermediate* (temperate) *zones* are the zones (1) where the sun's rays are never vertical, (2) where the days and nights are very unequal, but where the sun is never above or below the horizon for 24 hours together, (3) where the amount of insolation is less, and (4) its annual range greater, than below the tropics.

The *polar zones* are the zones (1) where the days and nights are sometimes more than 24 hours long. They are the zones (2) of least annual insolation, and (3) of greatest range of insolation in the course of the year.

According to this definition of the zones, the tropical zone is about 47° wide, each of the intermediate zones about 43°, and each of the polar zones about 23½°.

This classification is simple, but the limits of the zones do not always separate one sort of climate from another. Thus the climate of the belts where the trade-winds blow is much the same everywhere; but the trades extend beyond the tropics.

Zones defined by winds.[1] If climatic zones be defined by the direction of prevailing winds, the *tropical* (or *trade-wind*) *zone* is the zone where the trade-winds blow. It extends somewhat beyond the tropics, even to latitudes of 30° or 35° on the eastern sides of the oceans. The *intermediate zones* lie poleward from the trade-wind zone, and are characterized by prevailing westerly winds and variable climate, but they have no definite poleward boundaries. If definite poleward boundaries must be assigned, they might be placed at the polar circles, though the westerlies appear to prevail beyond them.

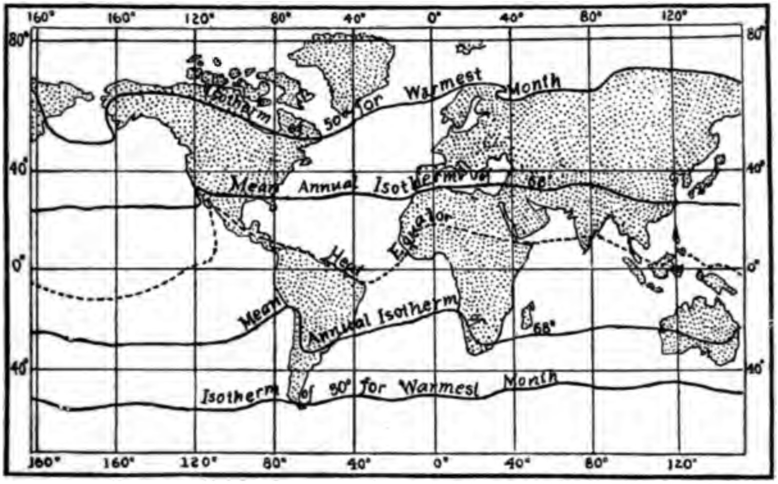

Fig. 440.—Zones defined by temperature, in degrees Fahrenheit. (Supan.)

This definition of zones places the dividing-line between the tropical and intermediate zones where the simple and uniform climate of the trade-wind zone gives place to the more variable climate where the westerly winds prevail. The classification is less simple than that which makes the tropics and the polar circles the boundaries of zones. Thus the zone of the trades shifts north and south with the seasons. Places near the poleward borders of the trade-wind zone are sometimes in that zone, and some-

[1] Davis, Elementary Meteorology.

times in the zone of the westerly winds. This annual shifting of a place from one zone to another may not be simple, but it corresponds with actual climatic conditions. If this classification leaves the zones with rather vague boundaries, it is because Nature has left them so.

Zones defined by isotherms. If the zones be defined on the basis of temperature, the dividing-lines between zones are isotherms. One division which has been suggested makes the annual isotherms of 68° the equator-ward limits of the intermediate zones, while their polar limits are the isotherms of 50° for the warmest month (Fig. 440).

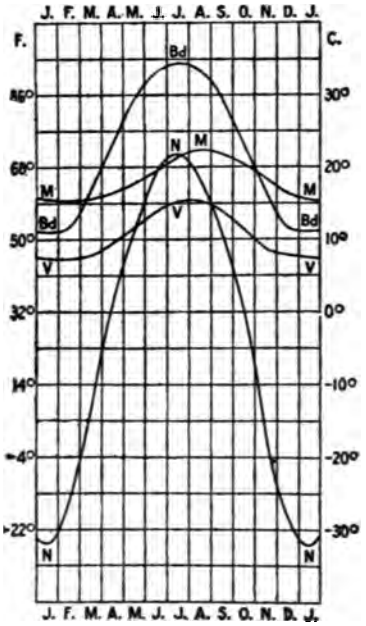

Fig. 441.—Graphs to illustrate oceanic and continental climates in different latitudes. *M* = Madeira, *Bd* = Bagdad, *V* = Valentia, and *N* = Eastern Siberia. (Angot.)

On the whole, this seems a fairly satisfactory basis for the definition of climatic zones.

Subdivisions of the Zones

Each climatic zone has at least two principal subdivisions, ***a continental*** and ***an oceanic.*** The oceanic climate of any zone prevails where there are extensive areas of water, and the continental climate prevails elsewhere.

Oceanic climates.[1] Oceanic climates are less variable than continental climates. Between the latitudes of 0° and 40°, the daily range of temperature is only 2° to 3° over the sea. It is far more on land. The annual range of temperature over the sea is also much less than that on land. This is illustrated by Fig. 441, which shows the yearly variation on the island of Madeira (curve

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[1] The classification of climates on the bases here considered, is well discussed by Ward. Bull. Geog. Soc. of Am., 1906, p. 401.

M, about 13° F.), and at Bagdad (curve *Bd*, more than 40° F.), in Asia Minor, both in rather low latitudes (about 33°). The former represents a marine climate, the latter a continental climate. In higher latitudes, the differences are still greater, as shown by the curves *V* and *N*. The former represents the marine climate of Valentia, on the southwest coast of Ireland (lat. about 52°, temperature range about 14° F.), and the latter the continental climate of eastern Siberia, somewhat farther north (range more than 90° F.).

The change from the cold of winter to the warmth of summer, and from the warmth of summer to the cold of winter again, is called the *annual march* of temperature. The sea retards the annual march of temperature more than the land does. Over the sea, therefore, the springs are colder and the autumns warmer than on land in the same latitude. The humidity of the oceanic climate is greater than that of continental climates. This results in more cloudiness, and often in more rainfall, especially in winter. The winds of the sea are, on the whole, stronger than those of the land. The leeward shores of the oceans (the shores to which winds blow from the sea) have climates which are essentially oceanic. The less variable temperatures, and the greater amount of moisture on such coasts, affect both plant and animal life. These effects go beyond the mere facts of life and death of the animals and plants, and even beyond the question of their thrift. It affects the quality of their seeds, tubers, etc. For example, wheat grown in a marine climate has less nutrition than wheat grown in a continental climate. Potatoes grown in the arid West, where the necessary (but no unnecessary) water is supplied by irrigation, are more valuable for food than those grown in moister climates.

Continental climates. In contrast with marine climates, continental climates have greater annual and daily ranges of temperature, and the seasons lag less than over the sea. In high latitudes the skies are clearer, and the winters colder; in low latitudes, the winters are warmer than over the sea. The humidity is less, the rainfall is less, and the rain less frequent in the interiors of the continents than over the sea; but the amount and distribution of rain is influenced by topography, winds, etc. The air over continents is drier and dustier than that over the sea.

A desert climate is an extreme sort of continental climate. Here the daily range of temperature is great. Winds are high by day, and the air dusty, often so dusty as to make travel difficult. The nights are calmer and cooler. As a result of the great daily range of temperature and the high winds, rock breaking due to changes of temperature (p. 40), and the transportation of dust and sand by the wind (p. 31), are at a maximum. The dryness is hostile to plants, and therefore to animals.

The *littoral* (coastal) *climate* on the windward side of the continent is very like the oceanic climate of the same latitude. In the zones of westerly winds, therefore, west coasts have oceanic climates, and east coasts have continental climates. In the zone of trade-winds the east coasts have oceanic climates.

The climate of the littoral zones is sometimes influenced by monsoon winds. So important are these winds that it is proper to speak of a *monsoon climate*. Monsoons are generally on shore in summer, and so give summer rains if the lands are high.

Mountain and plateau climates differ from other continental climates because of (1) the greater insolation and radiation which go with increase of altitude, (2) the less absolute humidity, (3) the lower temperature, and (4) the greater frequency of precipitation, especially in mountains, up to certain altitudes.

Mountains, like oceans, have relatively pure air and high winds. They modify general winds, and give rise to local winds (p. 358). They interfere with free horizontal movements of air, so that pressure and moisture conditions may be quite different on opposite sides of a mountain range.

Climatic effect of forests. Forests have some influence on continental climates. They lower the summer temperature by increasing the radiating and evaporating surfaces, and by increasing the cloudiness. They increase the relative humidity of the air, but it seems to be uncertain whether they have much effect on precipitation. In any case, they tend to hold back the water after it falls (that is, they retard the immediate run-off, p. 46), and to retard the melting of snow, so that their general effect on the moisture of the region is much the same as it would be if the precipitation were increased. Forests also afford protection against winds.

THE CLIMATES OF THE SEVERAL ZONES

The Tropical Zone

The first characteristic of the climate of this zone is its high temperature, with the oceanic climate more uniform and less warm than the continental.

The prevailing winds are easterly,— northeasterly in the northern part of the zone, and southeasterly in the southern part,— with a zone of calms (the doldrums) between (p. 398). As already stated, the trade-winds are generally dry winds (p. 397). Many lands in their path, such as the Sahara and part of Australia, are desert; but where they blow over mountains or plateaus, they yield moisture to them, especially to their windward sides or borders (p. 398). The abundant rainfall on the east slope of the Andes, on the tableland of Brazil, and on the higher parts of the Hawaiian Islands, are illustrations. Even in the Sahara, there are mountains which occasion rain enough to support forests, but the streams from the mountains soon disappear in the desert.

Moonsoon winds are often strong in the tropical zone, and in places give rain to regions which would otherwise be dry. Since monsoons generally blow from sea to land during the warm season, the monsoon rains generally fall at that time. Monsoons which blow from the sea over low lands yield much less rain than those which blow over high lands.

The tropical zone does not depend entirely on winds for its rainfall. Rainfall and cloudiness increase toward the center of the zone, while the strength of the winds decreases. In the doldrums, the rising air of the convection currents carries up abundant moisture, which, on cooling, is condensed and precipitated, giving daily (afternoon) rains. In this belt flourish the forests of the Amazon and of middle Africa. Since the belt of calms shifts a little with the sun, the zone of daily rains also shifts. A place which is in the belt of daily rains at one time of the year may be in the path of the trades at another, and may therefore have alternating wet and dry seasons. It should be understood, in this connection, that the wet season is a season in which there are showers, not a season when it rains all the time, or even a large part of the time.

Near the poleward borders of the tropical zone, also, there is likely to be variation in rainfall, for places here are in the zone of dry trades in the summer, and in the zone of variable winds in the winter. In neither case, however, are they favorably situated, so far as winds are concerned, for heavy rainfall. The most pronounced desert of the whole earth, the Sahara, lies near the poleward border of the trade-wind zone.

Along the coasts of tropical lands, the temperature is modified by the daily sea-breezes, as well as by the monsoons.

The range of temperature in the tropical deserts is considerable. The average annual temperature of the Sahara is about 80° F. The tempearture of the warmest month averages about 90° F., and that of the coldest about 70° F.; the annual range is therefore relatively slight. But the yearly extremes of temperature are far greater, for it sometimes reaches 120° F., and sometimes drops to 50°. Great as this range is, it is far less than that of most inland places in the intermediate zones, where extreme ranges of 120° are not uncommon.

Climate of Intermediate Zones

The average temperature of the intermediate zones is lower than that of the tropical zone, their annual range of temperature is greater, and their daily range, on the average, less.

These zones receive from the sun less heat per square mile than lower latitudes, where the rays are more nearly vertical. This explains their lower average temperature. The range of temperature from season to season is greater than in the tropical zone, because of (1) the greater inequality of day and night, and (2) the greater range in the angle of the sun's rays, and therefore greater variation in their heating power. In latitude 45° there are, at the maximum (summer solstice), about 15½ hours of sunshine (and heating) and 8½ hours of night (and cooling), while at a minimum (winter solstice) there are but 8½ hours of sunshine, with 15½ hours of night. Not only this, but when the days are longest, the sun's rays are most nearly vertical, so that the heat received in an hour is greatest when the days are longest, and least when they are shortest (Fig. 359). The result is that the summers, even in the latitude of 45°, may be very hot, while the winters are very cold. The summer heat, at its maximum, is not less than that of the tropical zone; and the winter cold, at its severest, is frigid. The annual range is greater in the higher latitudes of this zone than in the lower.

These great extremes of annual temperature, and the sudden changes of temperature and of humidity which accompany the passage of cyclones and anticyclones, make the term "temperate" singularly inappropriate for the intermediate zones.

The cold winters and the hot summers of intermediate latitudes have their effect on the temperature of the springs and autumns respectively, as already pointed out (p 343.). This point is of so much importance that it will now be stated with greater fullness.

During the winter the ground is cooled, and in the higher latitudes of the intermediate zones, the water in the ground is frozen to the depth of several feet. The frozen water in the ground may be looked on as "stored-up" cold. Snow which falls on the land in winter, and the ice which forms on lakes and ponds, have the same effect. So long as the ground is cold, the air next to it cannot become very warm. When the lengthening days of spring come, with their less oblique rays of the sun, the snow and the frozen water in the ground must be melted, and the soil and rock warmed, before the air in contact with them can become very warm. In intermediate latitudes, therefore, the spring is retarded (lags) because of the snow, the ice, and the cold soil and rock. A simple analogy may be suggested: If a fire were built in a stove covered with ice, it would take much longer for the stove to warm the room than if the fire were built in a stove already warm; for the ice must be melted before the fire can warm the air about the stove.

In the early autumn, on the other hand, the ground is warm from the heat of the summer, some of which has been absorbed by the soil, the rock, etc. Warmth has been "stored up," and the warm ground helps to warm the air, so that, as the days shorten and the rays of the sun become more oblique, the temperature does not fall as fast as it would if the ground were not warm. Thus the effects of the summer's heat hold over into the autumn, as the effects of the winter's cold hold over into the spring. This general point may be stated in another way: The heat stored up in summer helps the insolation of September to keep the air warm as the insolation becomes less, while the cold stored up in winter helps to prevent the insolation of March from producing its full effect. Cold is more effectively stored up than heat, so that spring lags more than autumn.

The lagging effect produced by the storing up of heat and cold is shown by a comparison of the average monthly temperatures of individual places. The monthly averages for Chicago are as follows:

January,	24° F.	July,	72° F.
February,	25° F.	August,	71° F.
March,	35° F.	September,	65° F.
April,	46° F.	October,	53° F.
May,	57° F.	November,	39° F.
June,	66° F.	December,	29° F.

In studying these figures, it is to be remembered that the insolation of March is about the same as that for September; but September is 30° F. warmer than March. The average temperature of Chicago for March is much less than that for October, and 4° less than that for November. But the insolation of November is far less than that of March,— is, indeed, but little less than that of January, the coldest month of the year. Again, the insolation of May is but little less than that of July, but the stored-up cold from the preceding winter prevents the insolation during May from having as much effect as it does in July, after the cold stored up in the preceding winter has been more largely dissipated.

The lag of the seasons is greater in the higher latitudes of the intermediate zones than in the lower.

The climates of the northern and southern intermediate zones are very unlike. The difference is due chiefly to the greater extent of land in the northern hemisphere. The climate of most of the southern zone is oceanic, while the climate of much of the northern zone is continental.

Compared with the corresponding zone of the northern hemisphere, the cool summers are one of the striking features of the intermediate zone of the southern hemisphere. Cloudiness and humidity prevail, except in the lee of mountains. These characteristics of the climate are not favorable for agriculture, and the lands of the southern hemisphere in latitudes corresponding to those of London and New York are usually unproductive. This is because of the cool summers, rather than because of cold winters.

The average temperature of January and of July for the northern and southern hemispheres (all latitudes) is shown in the table which follows. It will be seen that the January temperature of the northern hemisphere is, on the average, 4.4° C. (about 8° F.) colder than that of the corresponding month (July) in the southern hemisphere, and that the average temperature for July in the northern hemisphere is 7° C. (12.6° F.) higher than that of the corresponding month (January) in the southern hemisphere. The mean for the year in the two hemispheres is but .3° apart.

	January	July	Difference	Mean
Northern hemisphere.......	8.0° C.	22.5° C.	14.5° C.	15.2° C.
Southern hemisphere.......	15.5°	12.4°	5.1	14.9°
Earth as a whole	12.7°	17.4°	4.7°	15.0°

The oceanic climate of the north intermediate zone is very much like that of the southern zone.

Westerly winds prevail in the intermediate latitudes (p. 388), and many features of the climate of these zones are determined by them. The effect of these winds on the climate of the United States has already been outlined (p. 400). Where they blow over land which is warmer than the sea (low lands in summer), they are *dry winds*, because they take up moisture; but when they blow over land which has a temperature lower than their own (most lands in winter, and mountains at most times), some of their moisture is condensed, and rain (or snow) falls. The windward slopes of high mountains in these zones are therefore well supplied with moisture, while plains to the lee of such mountains are generally dry.

The principles of this explanation may be applied to other lands in this zone. Thus, in South America, as in its companion continent to the north, the tempering and moistening effect of the westerly winds is limited to a narrow belt, for in crossing the high

Andes Mountains the air loses both the warmth and the moisture it brought in from the ocean. East of the Andes, therefore, the effect of the ocean is little felt, and these mountains separate climates of notably different types, just as the Sierras do in the United States.

In most of western Europe there are no high mountains facing the ocean whence the westerlies come, and the moist oceanic climate of the coast passes gradually into the continental climate of the interior, with its drier air and clearer skies.

Middle latitudes do not depend entirely on the westerly winds for their rainfall. Cyclones often furnish moisture (p. 410) where the westerly winds would bring none. Thus east of the 98th meridian in the United States the rainfall is generally enough for farming, though not supplied by winds from the Pacific.

The cyclone and the anticyclone are important factors in the temperature, as well as the precipitation, of the intermediate zones. They give us our greatest annual extremes of heat (during cyclones in summer) and cold (during anticyclones in winter). They are also the cause of the sudden changes of weather, and so are an element of the variable climate of these zones.

The prevailing westerly winds tend to carry the oceanic climate over onto the western borders of the continents. Hence the mild climate of the western coasts of both North America and Europe. On both these coasts the range of temperature, like that of the tropical zone, is relatively low. Blowing over the cooler land, the oceanic winds give abundant moisture, and often much cloudiness and fog, especially in the higher latitudes in winter.

The continental interiors of the intermediate zones have much greater ranges of temperature than the western coasts, and the ranges become greater with increasing distance from the ocean, and with increasing latitude. In Siberia, for example, in high latitudes and far from a western coast, are found the greatest annual ranges of temperature known.

The climates of the eastern borders of the continents are unlike those of the western borders. On the former, continental rather than oceanic climates prevail. The differences are made clear if the climate of Vancouver is contrasted with that of Labrador, and that of England with that of Kamtchatka, on opposite sides of a continent (see Pls. XXIII and XXIV). The comparison may also be made between England and Labrador, and between Vancouver and Kamtchatka, on opposite sides of the Atlantic and Pacific respectively. The contrast is greater on the opposite sides of the Atlantic than the Pacific, (1) because the tempering effect of the Gulf Stream on western Europe is greater than that of the Japan Current on western America, and (2) because the Atlantic opens more broadly to the cold Arctic Ocean, allowing more ice-water to pass down the eastern coast of North America than along the corresponding coast of Asia.

Questions. 1. How would the climate of North America be affected if the mountains of the west were shifted eastward (1) to the central part of the continent? (2) To the eastern border of the continent?

2. What would have been the effect on the climate of central Europe if there had been a high mountain range along the west coast of Europe?

3. What would have been the effect on the climate of South America if the Andes Mountains had been on the east side of the continent instead of the west?

Climate of the Polar Zones

The distribution of the sun's heat is more unequal in the frigid zones than in lower latitudes (p. 337). At the poles there is half a year of continuous night and half a year of continuous day. Between the poles and the polar circles, the inequality of heat distribution is less than at the poles, but still great.

Though the seasonal range of insolation is greater here than in lower latitudes, the annual range of temperature is often less than in some other places. This is because a large part of the surface is covered with snow or ice, and the heat received from the sun cannot bring the temperature of the surface above 32° F., so long as the snow and ice remain. Where these conditions exist, the summer temperature of the air is raised but little above the freezing-point. Where the land is free from snow during the warm season, on the other hand, the annual range of temperature is great. The daily range of temperature is, on the average, not so great as in lower latitudes.

Precipitation in the polar zones is not usually heavy, and much of it falls as snow. Where the surface is continually covered with snow or ice, the precipitation is generally heaviest in the summer. The winds are then more heavily laden with moisture, and blowing over the surface of snow and ice, the air is cooled to the dew-point or below. Because of the low temperature of winter, the air of that season contains but little water vapor, and so gives but little snow.

Rainfall and Agriculture

The amount of rain which is necessary for agriculture varies (1) with the crops to be raised, (2) with the temperature of the regions, and (3) with the distribution of the precipitation through the year. The higher the temperature the more the rainfall necessary for growing plants. A few inches of rain in temperate latitudes would be enough for crops, if it fell just when the growing crops needed it. With the existing irregularity of rainfall, the amount should not be less than 20 inches per year in middle latitudes to make crops at all sure. Even more than this is necessary in the lower latitudes of the intermediate zone. Of this amount, much should fall in the season when crops are growing.

In the cultivation of semi-arid land, care should be taken in the selection of the crops to be raised.

Hann calls attention to the fact that in Jamaica and the Barbadoes the sugar crop can be calculated with approximate accuracy from the amount of precipitation. In South Australia, land which has 8 to 10 inches of rain will support 8 or 9 sheep to the square mile. In New South Wales, 4 inches more of rainfall will allow the land to support 96 sheep per square mile; an increase of 7 inches more (20 inches in all) will allow an equal area of land to support 640 sheep. In Argentina, with 34 inches of precipitation, land will maintain 2,630 sheep per square mile.[1] These figures do not take account of differences of soil.

Climate and life. The distribution of life is controlled very largely by climate. The dry deserts of low latitudes, the deserts in the lee of lofty mountains, and the snow deserts of polar regions are essentially climatic. Where rainfall is adequate and where temperature favors, life abounds wherever there is a proper soil;

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[1] Wills, cited by Hann.

and even the accumulation of a proper soil is influenced by climate. The best soil is worthless where water is wanting, or where the temperature is too low for plant life.

Of Australia it has been said: "Land without rain is worth nothing; and land in an Australian climate, with less than 10 inches a year, is worth next to nothing. Rain-water, without land, if the water can be stored in a reservoir and sent along a canal, is worth a great deal."[1]

It has been pointed out on earlier pages that great progress has been made in the last few years in learning how to cultivate land which has scanty rainfall in such a way that it becomes productive, even where it cannot be irrigated. These results have nowhere been more successful than in eastern Colorado and western Nebraska.

From the human point of view, winds are an important element of climate. Calms are enervating and winds stimulating. Winds are of great importance to health where population is dense, for they blow away the dust and other impurities which tend to gather about cities.

Changes of Climate

Within historic time. The records of climate, covering as much as a century for some parts of our country, afford little basis for the popular notion, especially among elderly people, that the climate is changing. One reason for this rather common idea is that there seems to be a tendency to exaggerate the striking features of exceptional seasons. The winters of heavy snow, or of intense cold, are the winters which are best remembered. Another reason for the notion that climate is changing is that people change their place of residence, and compare the climate of the place where they once lived, perhaps New York, with that of the place where they now live, perhaps Iowa.

Variations in rainfall, temperature, etc., do occur in short periods. Thus there seems to be a faintly marked weather cycle of about eleven years, corresponding to the sun-spot cycle. A longer cycle of about thirty-five years is indicated for Europe, where records have been kept longer than in our own country. Within this cycle there may be said to be two focal periods of a few years each, one when the rainfall is above the average and the temperature below, and the other when the rainfall is below the average and the temperature above. The basis for this cycle is not yet known.

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[1] Wills, cited by Hann.

Variations of this sort affect the movements of glaciers. This has been observed especially in connection with the glaciers of the Alps. They advance *after* (commonly some years after) periods of years of heavy precipitation and low temperature, and retreat after periods of years of light precipitation and high temperature.

Certain historic facts have been thought to show changes of climate in some places since the beginning of the historic period. Thus regions once populous are now too arid to support a large population. This is the case in southwestern Asia and northern Africa, where there are ruins of aqueducts and irrigating canals in places where there are now no adequate sources of water.

In pre-historic time. There is abundant evidence of great changes of climate in the course of the earth's history. There have been at least three (probably more) periods, widely separated in time, when there were glaciers where glaciers do not now exist. During some of these periods there were extensive glaciers in low latitudes, even in regions which now have tropical and subtropical climates (India, Australia, South Africa, and South America).

Warm climates, on the other hand, have persisted for long periods in polar regions, even down to relatively recent times. Thus Greenland enjoyed a warm climate not long (geologically) before the development of its present ice-sheet, as shown by the remains of plants, such as magnolias, which once grew there. It seems probable that the climate of the present time is cooler, and has a greater range of temperature, than has been common throughout the larger part of the earth's history.

Repeated changes in humidity seem to be as clearly indicated as changes in temperature. Regions which have moist climates now (e. g., New York and Ohio) have been arid at times in the past, and regions which are arid now (e. g., Arizona) have enjoyed moist climates at times in the past. The former aridity in the first case is shown by salt and gypsum deposits, and the humidity in the latter case is known by conclusive evidence of luxuriant plant life in regions which are now nearly desert. There are, for example, extensive "petrified forests" in Arizona (Fig. 442). These are areas where many petrified logs are found, buried in the clay and sand, which were deposited here after the trees grew.

From what is now known of the climates of the past, it seems clear that causes have long been in operation which bring about variations both in temperature and humidity. These causes have been thought to be (1) *geographic*, and due to the changes in the relations of land and water, or to changes in the topography of the land; (2) *astronomic*, due to changes in the shape of the earth's orbit, etc.; and (3) *atmospheric*, due to changes in the constitution of the atmosphere. Still other causes have been conjectured. As the facts concerning these changes are studied, they seem to be pointing to the third of these lines of explanation as the most probable. It cannot be said, however, that final conclusions have been reached.

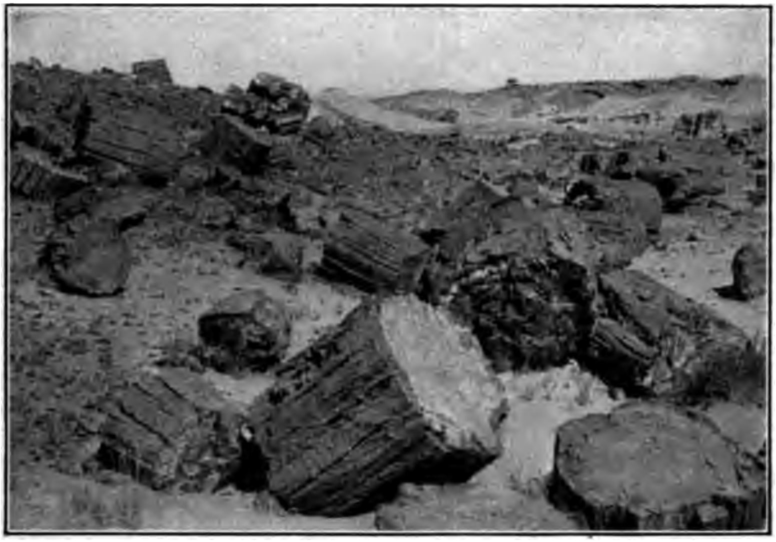

Fig. 442.—A scene in the so-called petrified forest, near Holbrook, Arizona.

CHAPTER XIX

PHYSIOGRAPHY, AND ITS EFFECT ON PLANTS AND ANIMALS

THE RESPONSE OF PLANTS TO SOIL AND CLIMATE

BY HENRY C. COWLES, PH. D.

Nobody would search a pond for a cactus nor a desert for a water-lily. Yet not every one can say why such a search must be barren of results. Whatever the cause, it is a matter of the most familiar observation that each type of plant has its own habitat, or place of growth. Some plants are very restricted in this respect, as in the case of those which grow only on limestone, or only in peat-bogs. Others, as the dandelion and field horsetail, can grow in many situations. Perhaps the majority of plants are able to live in a rather wide, but by no means universal, range of conditions, and are thus intermediate between the restricted limestone or bog plants on the one hand, and the plants which live nearly everywhere on the other. Common illustrations are the white oak, which may grow in sand or clay, and in the woods or in the open; the white ash, which is equally at home in swamps, along rivers, or in woods. The beech, which in nature is confined to deep rich woods, is a tree of relatively restricted range.

To understand differences in the distribution of plants, one must appeal to (1) differences in the life and structure of the plant, and (2) to the environment. Some trees, as the pine and spruce, are evergreen, while others, such as the maples and many oaks, are without leaves for a large part of the year. It can scarcely be doubted that such a difference in life-habit must affect the distribution of the tree. Still more clear does this become when one compares our deciduous trees (trees whose leaves fall in the autumn or winter) with the tropical evergreens, such as palms and bananas.

Evergreens with large delicate leaves could not endure the cold of winter; and so most of the trees native to the northern United States where winters are cold are provided either with small and tough leaves capable of enduring winter weather, or with delicate and commonly larger leaves, which are dropped at the beginning of the cold period. In a similar way, arid regions have plants that possess remarkable adaptations which fit them to live through long periods of drought. Almost every plant in a desert will be found to have some striking means by which it may get water, or retain it. Indeed, it is clear that only plants which already possess, or are able to get some sort of adaptation to drought, can live in a desert. A pond furnishes conditions that are in most respects the exact opposite of those found in deserts, and so it is not surprising that the plant species are altogether different in the two places, or that the structures of the plants are wholly unlike. A plant fitted to grow in the water commonly has spreading leaves, which are so thin that the plant usually wilts as soon as it is removed from the water. These facts show clearly that the chief factor in distribution is that of *adaptation*, and that one of the most important reasons why a plant grows in one place rather than in another is because of its structural limitations.

Another very important factor in distribution is the struggle for existence. While plants can grow only in places to which they are adapted, or to which they can become adapted, it does not follow that they occupy all the space where the physical conditions are such that they might thrive. A lawn of blue-grass may be so dense that no other plant can get a foothold there; yet if the blue-grass were removed, a host of other plants would soon take possession of the ground. Countless millions of seeds go to waste because they fall on soil unfitted to their germination or subsequent development; but other countless millions go to waste because they fall on ground that is already occupied by other species. The same principle is illustrated also in the case of species growing side by side under the same conditions. If a creeping perennial like white clover, and an annual like the ragweed, get an equal start in a new area, it usually happens that the white clover has possession of the area in a few years. This is not because the ragweed is not adapted to the place, but because the white clover crowds it out.

Many factors affect plant distribution. The more important are (1) water, (2) temperature, (3) light, (4) air, and (5) soil.

Water. No other agent seems to have so great an influence as water in determining the distribution of plants. This is partly because plants require water in the building up of their tissues, but very much more because they constantly lose water through evaporation from their exposed surfaces. These losses are so great as to seem almost incredible. In a single day a shrub or small tree may lose quarts of water, and a large tree may almost be said to lose barrels (p. 360). The structures of some plants are such as to reduce this great loss of water. Such structures are thick and impermeable skins, corky bark, coats of hair, and the like. Plants with small leaves or no leaves evaporate less than those with a great expanse of leaves. And so it is found that plants which are so constructed as to lose but little water, and plants with an unusual ability to get water or to store it, are the kinds that can grow in deserts, on rocks, or in dry sand. The plants of ponds and swamps, on the contrary, and even the plants of the woods, commonly show few or no such adaptations.

The water in the soil plays a great part in plant distribution, as may be seen in the gradation from a swamp to a meadow. Where water stands throughout the year, we find aquatic plants which collapse and die almost as soon as they are removed from the water. Where water stands a large part of the year, we find bulrushes, reeds, and cattails; where water stands only a small part of the year, sedges and rushes are found; and where water almost never stands above the surface, meadow-grasses abound. Each plant species appears to be attuned to its own particular water need. Less than its proper supply means injury, and perhaps death; more than the proper supply means danger of drowning.

Atmospheric moisture is also of great importance in the distribution of plants. To this, perhaps more than all else combined, the large features of the world's vegetation are due. Speaking broadly, one may divide the vegetation of the earth into forest, prairie, and desert, and it is not difficult to show that these features are determined largely by differences in humidity and rainfall. Especially is this true of the forests and deserts. Not only this, but among the various types of forests, many are what they are because of differences in atmospheric moisture. Thus in the tropics, deciduous forests are found in regions of periodic rainfall (wet and dry seasons), and evergreen forests where all seasons are rainy. So important do most plant geographers regard water as a factor in the distribution of plants, that their primary classification of plants is based on this factor, and the vegetation of the globe is divided into the *hydrophytes,* or water and swamp plants, the *xerophytes,* or plants of arid climates and soils, and the *mesophytes,* or plants of situations that are intermediate as to moisture.

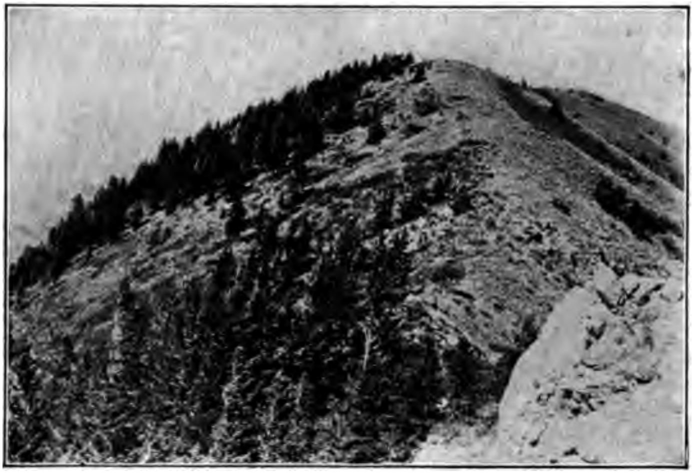

Fig. 443.—Mountain slope in Utah, showing the influence of atmospheric moisture on plant distribution. The trees are here confined to the west slopes. In this region the rain-bearing winds are from the west. (Photograph by Praeger.)

Temperature. Formerly, heat was regarded as the chief factor in the distribution of plants and animals, and the primary climatic division of the world into *torrid* (=tropical), *temperate* (=intermediate), and *frigid* (=polar) zones is a relic of this notion. Temperature plays so large a part in human calculations that it was assumed that plant distribution must be largely determined by it. Heat plays a large part in the growth of plants, as illustrated by the differences of plants in late and early seasons. It is possible to show that each plant species has its own upper and lower limits of temperature within which it may thrive, and a very much larger range within which it may exist. These facts show that certain plants are confined to tropical regions, while others are able to thrive in the coldest places known. Because of this, figs, bananas, most palms, and tree-ferns are confined to warm climates. It is not so clear whether plants that are confined to temperate and cold regions grow there from choice or from necessity. Temperature is of much greater importance as an indirect than as a direct factor. The plants of alpine and polar climates are well known to possess somewhat the same adaptations that are found in plants of dry regions. Some have thought that such adaptations protect against cold, but it has not been shown that this is the case. It is much more likely that these adaptations are of advantage in checking the excessive loss of water, just as in deserts. Because of the cold or even frozen soil, the plants are able to absorb less water; hence it becomes important to conserve the little they are able to get. Thus we find that most plants without such adaptations are excluded from cold regions. Temperature, then, is of chief importance as it affects the water supply of the plant.

Light. It has long been known that green plants are dependent upon light for their successful growth, and that the manufacture of the fundamental plant foods is possible only in the light. Plants differ widely among themselves in the amount of light needed to carry on their activities. From this standpoint, plants are often divided into *sun plants* and *shade plants*. The plants of the prairies would be regarded as sun plants, and the plants of deep woods are good illustrations of shade plants. It is probably true, however, that the death of a shade plant when it is taken out into the strong sunlight is due more to the rapid evaporation of water than to the direct influence of the sunlight. Hence it is likely here, as in the case of temperature, that the light acts rather as an indirect influence, and that it is the increased loss of water that makes the plant suffer.

Air. Plants use the oxygen of the air in respiration, and the carbon dioxide in the manufacture of starch and sugar. They use nitrogen in the manufacture of proteid, but the nitrogen they use is taken from the soil and not from the air directly. The air is not of great importance in the distribution of plants, because it is essentially uniform in time and place. Small as is the amount of the carbon dioxide, and great as is its use, there is yet enough for all plants everywhere (p. 329). It is much the same with oxygen, except in the case of plants growing in stagnant ponds and swamps. Here certain plants are kept out because of the great amount of oxygen they require. The influence of the low pressure of mountain atmospheres on plants is not known. Indirectly, of course, the rarity of the air makes the light more intense, and the temperature extremes greater.

Soil. The soil is a complex substance made up of water, air, and earth particles. The influence of soil-water, air, and temperature has been considered. It remains to speak of the chemical and physical influence of the earth particles. Different soils, such as sands and clays, have been observed to have very different floras. Similarly, different rocks have been said to have different lichens and different species of other plants growing on them. Soils and rocks differ chemically, and it has been thought that some plants require one type of soil to get their necessary food materials, and other plants another soil. But the fact that plants differ only slightly in the food materials they take from soils, and that nearly all soils contain all the necessary constituents in abundance, shows that the chemical composition of the soil is of very subordinate importance in the life of plants. Physically, the soil is of importance chiefly as it makes it easy or difficult for plants to get water. Sand plants are often somewhat like desert plants in their adaptations, and it is because of the low water content of sandy soils that plants with protective structures do better there than plants without such structures.

Topographic changes. In the preceding paragraphs it has been assumed that the external world is stable,— that it is made up of a number of habitats, such as ponds, hills, etc., and a number of climatic types. It has been assumed also that each soil and climate has its own peculiar plants, and so far as any of the above-mentioned facts are concerned, these plants or their progeny might remain in these habitats forever. But the topography of any region is undergoing constant and often rapid changes, due partly to the work of wind and water, and partly to the plants themselves. These changes are especially evident along rivers, in ponds, and along the shores of oceans or great lakes. It is worth while at this point to specify some of these changes and their influence on plant life.

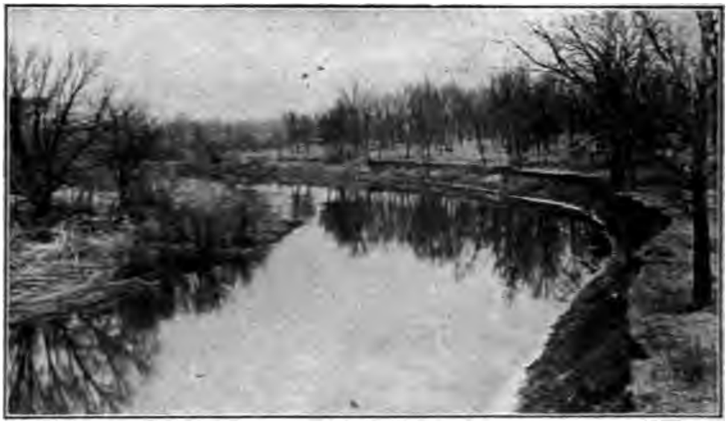

Fig. 444. —The Desplaines River near Chicago. To the right, the river is eroding, and destroying an upland forest. To the left, the river is building up a flood plain, on which a new plant society of willows and giant ragweeds is appearing. (Photograph by Land.)

One of the most obvious topographic changes is the filling of a pond. This is due in part to the silt that is brought in by in-wash, and in part to the accumulation, at the bottom of the pond, of plants and animals as they die. Many ponds have little in-wash, and in such cases the accumulation of plant and animal débris is almost the sole cause of the filling of the pond. Many pond plants are adapted to a particular depth of water, and as the water becomes shallower year by year, it becomes more difficult each year for deep-water plants to live in the pond, and at the same time easier for the plants which are adapted to shallower water. We may even go so far as to say that the pond species are making the pond less favorable for their own kind, and more favorable for other species. Consequently we may speak of a normal succession of life in a pond, and we may see in most ponds the advance of the land vegetation into the area formerly occupied by water plants. Very frequently this advancing margin is made up of bulrushes, reeds, and cattails. These latter plants in turn build up the soil, and prepare the way for the destruction of their own kind, and the advance of other vegetation, perhaps that of a sedge swamp.

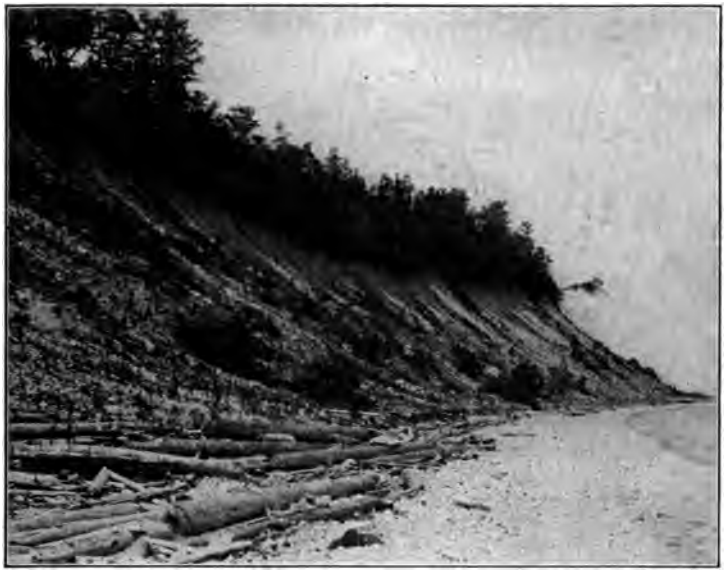

Fig. 445.—A clay cliff on Manitou Island in Lake Michigan. The lake has recently eroded at this point. Note the toppled tree in the distance. The stopping of erosion has enabled vegetation to get a foothold on the cliff. (Photograph by Thompson.)

Along the shores of oceans and great lakes there are great stretches in which the water is eating away the shore, and thus advancing on the land. In other places the waters are making sandy beaches, and sometimes the winds take the sand from the beach and pile it into dunes. Where the shore is being eroded by wave action, especially where the bluffs are of clay, most plants are unable to retain a foothold unless the erosion is slow. Not only is the situation one of great exposure, and hence ill-suited to the majority of plants, but the instability of the soil is such as to cause plants to slump off into the water and die. A few short-lived annuals, and some perennials that can adapt themselves by burrowing back as the bluff recedes, may be found in such places.

In a region of sand dunes, we find remarkable adaptations of plants to their surroundings. In the first place, many dunes are formed through the agency of plants, since the plants furnish the necessary obstacle for the accumulation of the sand. The most striking dune phenomena are seen where a moving dune is advancing over an area occupied by vegetation. Here the responses of the various plants are both unique and diverse. Many plants die at once; this is true of most herbaceous plants, and of some trees, especially pines and oaks. Indeed, these trees often die before they are completely buried by the sand. The cottonwood, the osier, dogwood, and several species of willow, on the contrary, grow with extraordinary vigor, and keep above the encroaching sand unless the advance is unusually rapid. Some of these plants

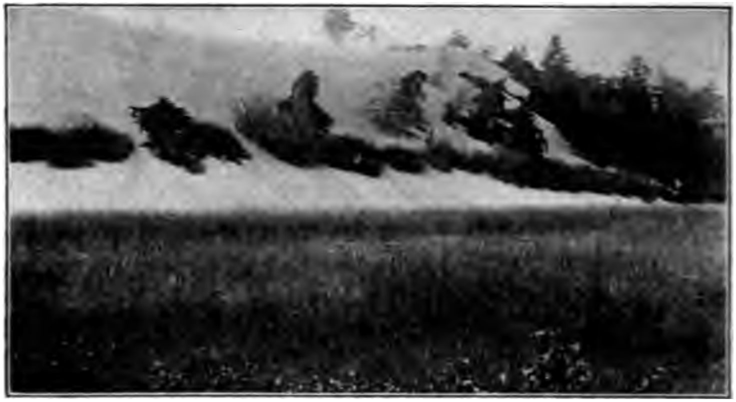

Fig. 446.—A dune advancing over a swamp at Dune Park, Indiana. The willows and dogwoods of the swamp are stimulated to a growth more vigorous than normal, and are keeping above the advancing sand. (Photograph by Cowles.)

appear to grow more luxuriantly than before. A large number of trees, as the linden (bass) and elm, endure a surprising amount of sand burial without much injury, and yet are not stimulated to extra growth. Still another class of plants germinate in the dune sand, and maintain there a more or less precarious existence.

Forests have been shown to change from generation to generation, owing to the changed conditions of the habitat. The first generation is often made up of poplars, birches, or pines, which can grow in poor dry soils, and in well lighted places. Year by year these trees cast a denser and denser shade, thereby making the conditions harder for their own kind. They also cause the accumulation of forest mold, whereby the soil is made richer and moister, and hence more favorable for such trees as oaks, which are also favored by the greater shade. In a similar way, the increasing shade and mold of the oak forest tends to make conditions that favor such trees as beeches, maples, and hemlocks. There are reasons for believing that such a forest is the ultimate type of vegetation toward which the northeastern United States is tending. The plant geographer views such a type of forest much as the physiographer views the base-level, as a sort of final stage closing the normal series of changes through which the region passes.

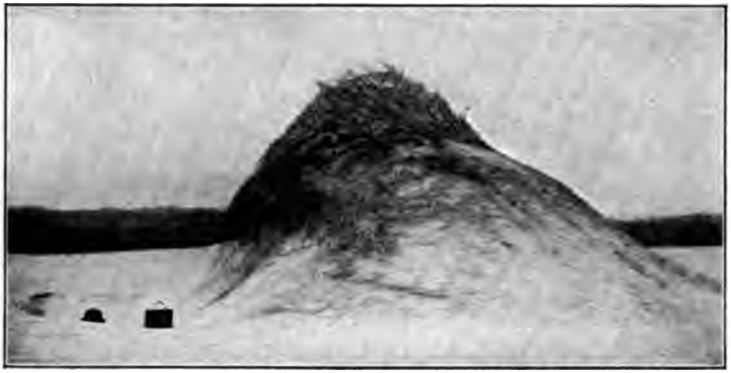

Fig. 447.—A mound of sand held in place by the sand-reed, which is hence known as a sand-binding grass. Dune Park, Indiana. (Photograph by Cowles.)

The relation of plant geography to man. Man depends, directly or indirectly, upon plant life for all his food and clothing, for lumber and fuel, and a thousand other things of value. It is therefore evident that the natural distribution of plants is of primary importance to man's welfare. In the earlier ages, this dependence seemed closer than it does to-day. At the outset, man must have obtained the necessaries of life from untilled nature, and his development must have been restricted in many places, because of its slight contribution to his needs. As years passed, man came to cultivate useful plants more and more, and became less dependent upon natural plants, except in the case of trees used for timber. But with all the progress of modern agriculture, there yet remains a close dependence of cultivated crops upon the same conditions that affect wild plants. Many plants of value, such as figs, bananas, pineapples, oranges, and cotton, are restricted to warm climates. Cocoanuts are not only restricted to warm climates, but to maritime regions as well, while most forage grasses and cereals reach their highest development in the temperate regions.

The influence of the soil conditions on cultivated plants is equally evident. Nearly all common crops are most successful in soils of intermediate moisture; i. e., most cultivated plants are mesophytes. Arid conditions and great soil moisture are almost equally detrimental in most cases. Rice, a tropical swamp cereal, furnishes a conspicuous exception to the general rule. Some varieties of wheat have been produced that are able to endure unusually dry soils, and the so-called "dry farming," which permits but little of the soil-water to go to waste, makes possible a still greater extension of agriculture into dry regions. As a rule, however, mesophytic soils and temperate or tropical climates have supplied most of the plants which man finds useful. In the future, it is likely that many of the methods of the employment of plant life by man will change radically. The forests are being rapidly destroyed, and man in the future must more and more cultivate his forest trees, or use iron or other substitutes for wood. As population increases, farming must be carried on more carefully. New inventions must secure a greater yield per acre, new plants of use must be discovered or created, and some method must be found to cultivate semi-desert regions and other regions hitherto unused.

THE ENVIRONMENTAL RELATIONS OF ANIMALS

BY CHARLES C. ADAMS

1. *The Organism and its Environment*

It is a matter of common knowledge that animals are adapted to the conditions in which they live. The harmony between them and their surroundings depends chiefly on two sets of conditions; (1) the *structure and habits* of the animals themselves, and (2) the *surroundings* or *environment* in which they live. The first of these may be called *internal,* the second *external.* Both the internal and the external conditions are complex. Thus the fish, with its gills, fins, etc., presents a complex internal organization which is necessary to the fish in its watery environment.

When animals are most perfectly adjusted to their surroundings, the individuals are abundant and perfectly developed. On the other hand, animals are influenced unfavorably by unfavorable conditions. Thus, in former years the buffalo or bison lived on the Great Plains in immense herds; but with the coming of the white man with his rifle, almost all of them were destroyed. Changes also take place in nature without the help of man. Thus a flood may wash away a gravelly riffle in a brook where darters lived, and at the same time make a similar riffle at some other point down stream. These small fish perhaps find and take possession of the new and favorable site. In such cases the change in the place where the animals live is a response to the changed conditions. For some animals similar changes may require a change of food, change of nesting-site, of habits, or even of color, as shown by the pale colors of many animals which have gone into deserts to live. Again, many animals change their habits and structure with age, so that their responses to the same conditions vary in the course of their lives. Thus the young of a dragon-fly lives in the water and breathes by means of gills; but when mature it lives and flies in the air and breathes without gills.

It is thus seen that there are important changes, both of living things and of their environment. The problem of life for animals is to use and adjust favorably (*correlate*) these two sets of variable conditions. These changes and adjustments are not limited to the present time and generation; they have been in progress for ages.

2. *The Principal Sorts of Environments*

Many factors are combined in the leading and typical conditions of life on the earth. Thus the combination of extensive basins, unstable water, certain salts, gases, seaweeds, etc., produce the *seas* and the *sea environment;* while the solid ground, composed of rocks, clay, sand, etc., more or less covered with vegetation and subject to variable climates, to weathering and erosion, with streams and lakes, gives the *inland environment.*

The ocean is the greatest animal *habitat* (place of living), both because of its great area, and because so great a thickness of it may be lived in by animals. Over the land, on the other hand, a thin stratum of the lower air is all that is densely populated, and below the surface of the land the life is very limited. The upper waters of the sea and the surface of the land are the most densely populated parts of the earth.

3. *The Marine Environment*

The ocean is generally considered to have been the original home of animal life. If this is so, all forms of animals found on the land have descended from forms which lived in the sea. Life is more abundant at the margins of the sea than elsewhere in it. Here, too, the environment is complex, because here the air, the land, and the sea meet and influence one another. The conditions seen from the shore of the sea do not represent the sea as a whole, for in addition to the open sea and the marginal (*littoral*) zone, there is a great hidden area, the deep sea, far beyond the light of the sun, where the water is cold (p. 497).

The marine environment may be divided into three parts: (1) the littoral or shore zone, (2) the upper part of the open sea, and (3) the deep sea.

(a) **Life of the littoral or shore zone.** Generally speaking, the conditions of life in the sea are much more uniform than on land. The temperature, especially, is subject to less sudden changes; but the conditions of life in the littoral zone are more like those on land than are the conditions in other parts of the sea. There is a great variety of animals found in the littoral zone, and it includes numerous kinds of coiled and bivalve mollusks, worms, starfishes, corals, sea-urchins, crabs, sponges, and many others. Many attached or *sessile* animals thrive in this zone, on account of the solid bottom and the supply of microscopic food which floats in the water, and they become, in turn, feeding-ground or pasture for various carnivorous (flesh-eating) animals. The animals of the littoral zone vary much in their habits. Some swim, others float; some burrow in the mud, and others are attached to the bottom or shore; some feed on other animals, and some on plants; and some must endure the ebb and flow of the tide. This is the part of the sea where water-birds, seals, etc., abound.

With differences of shore conditions go differences of animal life. Thus the life on a sandy beach differs from that along a shore composed of rock, and the life on such shores differs from that on a mud flat. The life along cold coasts, too, differs from that along warm ones.

(b) **The open sea.** Away from the shore, other conditions prevail. Out from the shore the rise and fall of the tides, the beating of the waves, and the sediment of the shore diminish and finally disappear, and the conditions of life become more uniform, because these ever-changing factors are absent. Still other influences tend toward uniformity. Thus the changes of temperature are slight compared with those of the land. The water at the surface is well lighted, but the light disappears rapidly below, and at the depth of a few fathoms is nearly absent. The open sea is the most extensive habitat favorable for animal life upon the earth.

In harmony with these conditions, the fauna (a term applied to all the animals of a given place or habitat) is composed largely of swimmers and floaters which live a life independent of the bottom. The smallest and the largest animals live here,— the innumerable microscopic forms and the whales which feed upon them.

Great numbers of individuals, rather than great variety of forms, are characteristic of this part of the sea. Below the surface, animals diminish in number.

Some naturalists consider that the original home of life was in the open sea, others that it was nearer to the shore. Whatever the original fauna of the sea, it has received additions from the shore and from the land in the course of time. On the other hand, it has contributed to both the shore fauna and to that of the deep sea.

(c) **The deep sea.** Below the surface of the sea, and beyond the continental shelves, there are great tracts, including more than half the area of the sea, where the water has an average depth of more than two miles. This great body of water is beyond the reach of sunlight, and is without all the higher kinds of vegetation. It is uniformly cold, with a temperature between 32° and 40° F. The weight of the overlying water, at the depth of about two miles, is measured by hundreds of pounds to the square inch. The bodies of many of the vast hordes of microscopic animals which frequent the open sea sink to the bottom when they die, and furnish food for great numbers of scavengers. The uniformity of the conditions, such as the low temperature, the darkness, the great pressure, the abundance of food, etc., make the bottom of the deep sea the most uniform extensive habitat upon the earth. This uniformity is occasionally interrupted by submarine volcanoes and earthquakes, but it is far beyond the influence of the changing climates of the surface.

Some animals live on the deep sea bottom. This is made possible by the unlimited supply of food of the sort mentioned above. The scavengers, in turn, furnish food for carnivorous animals, whose powerful jaws show that to eat without being eaten is a problem of the deep seas as well as of the land. The animal life of the deep sea is varied, including many kinds of microscopic forms, and a great variety of mollusks, crustaceans, and queer-looking fish.

Little is known of the means by which these animals came to be spread over the bottom; but the swimming and crawling forms, either when young or as adults, move about much as in shallow water. Feeble currents probably aid some forms in moving about.

The deep sea may be compared to a trap which is reached with ease, but one from which escape is difficult or even impossible. The deep-sea fauna appears to have invaded the depths from the waters above, in the course of past ages. Some of these animals may have gone down from the open sea, and some have reached the deep waters by creeping, crawling, and swimming down the slopes of the continental shelves. This deep-sea trap has been able to preserve the many prisoners which have invaded its territory, on account of its abundant food supply.

4. *The Inland Environment*

Of the three marine habitats, the littoral zone affords the conditions least unlike those of the land, for in the littoral zone (1) the temperature is variable, (2) there is a solid bottom on which many plants and animals rest, and (3) along the immediate shore there is wetting and drying with the rise and fall of the tides. On the land, some of the variable elements of the littoral zone become more pronounced, and new ones appear. There is, in place of water, the relatively dry air, and generally an abundance of plants. A food supply no longer floats about, as in the water, and most animals on land must lead an active life, and must search for their food. The seasonal changes of temperature, which are slight in the sea, are greater on land, and increase and become greater and more sudden back from the shores. Furthermore, the relief of the land produces greater diversity than the relief of the sea bottom. Temperature, humidity, insolation, and all the climatic differences between the equator and the poles are more pronounced inland than in the sea or along its shores.

In humid regions, lakes, ponds, and streams form an extensive and characteristic *fresh-water environment*. The arid and humid climates are quite distinct, and emphasize the fundamental contrast between the relatively simple and uniform conditions of life in the sea, and the varied, extreme, and severe conditions on land.

Another great difference between the marine and the inland environments is the erosion going on over the land; but all important geological agencies, such as diastrophism, glaciation, and vulcanism, must be recognized as factors which influence the land environment. Furthermore, these influences commonly have a certain definite trend which produces orderly changes in the environment, and therefore in plant and animal life. Thus as a mountain country is base-leveled, there are definite changes in the habitats, in harmony with each stage of degradation; and all these changes affect the life. Again, the small lakes of the northern states are tending to become extinct through the accumulation of vegetable debris and the in-wash of sediment (p. 218). In time the lake basins will be filled, and this aquatic (watery) environment and its life will disappear.

The vegetation of the sea has less influence on the animals of the sea than the vegetation of the land has on the animals of the land. Animals which live on vegetation are most abundant on land, while carnivorous animals are most abundant in the sea. This is surely a response of the animals to their conditions of life.

There is a common notion that animals are most numerous in the densest forests; but the fact is that dense, dark forests have relatively few animals. In the tropics, it is among and above the tree-tops, about the borders of the forests along the streams, and in the more open forests, that animals abound. The same is true of the forests farther north.

(a) **The fresh-water environment.** The fresh waters of lakes and streams furnish an environment in contrast with the dry land, though water grades into land through ponds and marshes. Some of the fresh water is running, and some is standing. In a swift brook, the constant onward movement of the water tends to wash away those animals which cannot stem the current by active powers of swimming, or by some method of holding fast. The sucking foot of snails, and the claws and hooks of many insects, help the animals possessing them to resist the currents. So does hiding under stones or in the bottom. In times of flood, vast numbers of the microscopic animals found in streams are washed into the sea and destroyed; but the life of their kind is continued in protected places from which they are not swept out. The dangers due to the rapid onward rush of the waters become less severe as streams advance toward topographic old age, and their currents become more sluggish. On the other hand, rapid waters are not only favorable, but even necessary to some animals, and as the swift-water habitat is reduced, conditions favorable for such animals become less general. At the same time there is an increase in the habitat of animals requiring quiet waters. The agitation of rapidly flowing water, with its surface broken by rapids and falls, insures an abundant supply of air in the water, and this is essential to many animals. Streams are more permanent than lakes and ponds, and this fact is probably related to the very old character of some fresh-water animals, such as the garpike, most of whose relatives lived during ages long past.

The faunas of ox-bow ponds and lakes, produced by meandering streams, are similar to the faunas of the streams which produced them, because they are stocked with animals from the parent streams during floods.

In contrast with the streams, the waters of lakes, ponds, and swamps are not in constant movement. Large lakes may have currents, but they are more or less circulatory, without the ever-onward motion characteristic of streams. Wind waves are the most characteristic motion of lake waters. In large lakes, wave action on the shores may be so severe that the more familiar sorts of plants and animals do not live there in abundance. For this reason, some shore lines do not possess conditions favorable for littoral faunas; but with the development of wave-cut terraces, spits, and bars, the conditions become more favorable, and the abundance and variety of the littoral fauna increase. In smaller lakes, the great abundance of vegetation bordering the water is of prime importance to some forms of animal life. It is to these margins that great numbers of fish go during the breeding season to deposit their eggs and rear their young.

The deeper Great Lakes present conditions in some respects like those of the sea. Thus there is (1) a *littoral*, (2) an *open-water*, and (3) a *deep-water* fauna. But these faunas are relatively poor when compared with those of the land or the sea. They are composed largely of microscopic animals, of crustaceans, mollusks, a great variety of the immature stages of insects, such as the young of may-flies, dragon-flies, and flies, many kinds of fish, and amphibious (able to live both on land

and in the water) animals, such as salamanders, frogs, and turtles, certain birds, etc.

The means by which the smaller fresh-water animals are distributed over the earth's surface are very successful, for many microscopic forms range over a large part of the earth. Many of the smaller animals, in some resting stage or as eggs, are able to endure much drying, so that they may be carried by the winds as dust, or they may be carried in the mud attached to birds and mammals. And last, but far from least, spreading has been effected by running water which, in the course of the ages, has worked over much of the land surface.

(b) **The land environment.** The conditions of life on land are very different from those in the sea and fresh water. In contrast with the sea and large lakes, the air in which the land animals live is rapidly heated and cooled, and is very easily moved. It is also of slightly variable density, and of very variable humidity. It therefore gives the most changeable and complex extensive habitat found upon the globe.

Climates are much more varied inland than at sea (p. 448), because the effects of all climatic factors are modified by topography, and by the more ready absorption of heat by the land. A good soil, with sufficient moisture, a favoring temperature, and light, supports an abundant growth of plants, which are essential to vast numbers of animals. The herbivorous habits of land animals are in marked contrast with the carnivorous tendencies of the marine fauna, as already noted.

The land fauna penetrates only the most superficial layer of earth — the part most abundantly supplied with air.

5. *The North American Inland Environments*

Geographic environments are formed by various combinations of climate, topography, vegetation, etc., just as the smaller units or habitats are formed on a smaller scale by water, soil, vegetation, etc. The larger environmental units are therefore only habitats on a larger scale; and the adaptations and responses of animals to these larger units, are as characteristic as are the adaptations and reactions to the conditions of life in smaller environments or habitats. The boundaries of any environment, either large or small, are barriers to animals not adapted to traverse them. For this reason, each large geographic environment is usually broken up into several minor units, and these again into special habitats.

In the following outline of the main geographic environments of North America, only the main characteristics of the several provinces, and their common and better known kinds of animals are mentioned.

(a) **The tropical environment.** The primary characteristic of the tropical environment is a high temperature throughout the year. In many places there is also an abundance of moisture, and when these two elements are combined, an environment is produced which favors great variety and great abundance of animal life. The life of the tropical forests is ever the source of wonder and admiration. On account of its abundance, it has become the standard of comparison for all other land environments. But we are not to infer that all tropical conditions are favorable to forests and animal life; for when sufficient moisture is lacking, the excess of heat makes desert conditions. It is true that desert conditions appear favorable to such animals as live there, but the small number and the small variety of animals which can endure desert conditions, shows the severity of these conditions.

The North American tropical environment lies south of the Mexican Plateau, and continues as narrow lowland strips to the mouths of the Colorado and the Rio Grande rivers on the west and east, with outlying colonies in the West Indian archipelago, and at the tips of the peninsulas of Lower California and Florida. This environment is one of relatively limited extent, and is largely confined to low altitudes. The humid parts of it are densely forested, but where the moisture is less, the vegetation becomes sparse and desert-like in appearance.

Palms, figs, mahogany, orchids, tree ferns, and mangroves are common tropical plants, and monkeys, armadillos, jaguars, tapirs, and innumerable birds, snails, insects, and other animals make up the exceedingly rich and varied fauna. The land-snail fauna of the West Indian archipelago is, for its area, the most varied and remarkable on the earth.

(b) **The dry plains and desert environment.** North of the tropics, an extensive, arid, subtropical, and temperate region begins with the Mexican Plateau, and extends northward about to the Canadian boundary on both sides of the Rocky Mountains, and into the central valley of California, and southward over most of Lower California. This extensive area is composed largely of plateaus and high plains, and has a great north-south range across many isotherms (Pl. XXII). It is arid throughout, although not equally so. Its water consists mostly of a few streams which flow through the dry regions from the mountains, and of others which are lost in the dry soil or in closed basins. These basins often contain salt or alkaline water. The clear skies, strong insolation, and rapid radiation of the more arid regions favor great daily changes of temperature, while to the north the seasonal changes are quite severe.

This region was only slightly invaded by the ice-sheet of the glacial period, and for this reason furnished a retreat for such animals as migrated before the on-coming ice, and could endure the relatively arid conditions.

The aquatic fauna of this region is peculiar and characteristic, especially the meager fauna of the salt and alkaline waters. The fish of the rivers, too, have many peculiarities. The land animals of this region formerly included the buffalo, prong-horn antelope, coyote, prairie-dogs, jack-rabbits, rattlesnakes, horned toads, and many others.

Some of the characteristic habits and responses of this fauna are of special interest. Like the desert plants, the desert animals are, as a rule, scattered. Few of them wander over great areas and feed on great pastures, though the bison did so, in lands which, though not desert, were somewhat arid. Less roving animals, even though they live in colonies, like the prairie-dog, are not uniformly abundant. On account of the hot days and cool nights, many of the animals of this region are more active during the night than during the day. Other species, as the antelope, are very fleet of foot, and still others burrow in the ground. The fleet-footed animals, accustomed to live in an unforested country, are very keen-sighted. Another characteristic of many desert animals is their light color.

(c) **The humid hard-wood forest environment.** This environment is found east of the arid plains, on low-lying lands, plateaus, and low mountain ranges, and extends north to the belt of cone-bearing trees (such as pines) near the Canadian border. It is produced by the combination of moderate temperature, abundant rainfall, a deep soil, and a luxuriant vegetation, including deciduous forests. In general, the conditions are so favorable for trees that forests tend to cover all the ground. The abundant vegetation provides an ample supply of food, so that insects and insect-feeding birds are plentiful. The moisture, temperature, and vegetation make favorable conditions for the numerous land-snails. Salamanders, turtles, and snakes are well represented, and altogether the region has an abundant and varied animal population.

The coastal plain on the eastern and southern borders of this environment presents conditions somewhat different from those of the interior. All these differences, such as the more open forests on the sandy soil, have their influence on the fauna.

The stream fauna of the humid, hard-wood forest region is unsurpassed upon the continent in abundance and variety. This is particularly true of the river mollusks, including both the coiled shells and the mussels, whose species are numbered by hundreds. Crawfishes show an abundance and variety not found elsewhere. The fish fauna is also well developed, and amphibious animals, such as frogs, toads, salamanders, and turtles, are numerous.

The land fauna is also large and varied, though it falls behind the aquatic fauna. The birds and mammals which live in forests are quite abundant, and the land-snail fauna is very rich for continental America. Only the northern part of this environment was invaded by the ice, so that it acted as an immense preserve for animals during the glacial period. From this tract, they spread to the north, after the glacial period.

(d) **The cone-bearing forest belt.** Bounded on the southwest by the arid western conditions, and on the southeast by the hard-wood humid tract, a vast area covered by a cone-bearing or evergreen forest (composed of spruce, pine, fir, etc., and a few kinds of deciduous trees, such as aspen and birch) extends northward to the tree limit. Outlying areas of this general environment are found on the larger mountains farther south; but to the north these conditions spread over the entire lowlands. This region was glaciated, and robbed largely of its residual soil, and it now forms the most extensive lake and pond area upon the globe. When the ice of the glacial period covered this area, it must have been an ice desert; but with the retreat of the ice, life crowded back into the region from the south, whither it had been driven by the growing ice-sheet.

The winters of this region are in general severe and long, and the summers correspondingly short. The rainfall is moderate, except near the Pacific coast, where it is heavy.

The fresh-water fauna of this region is abundant and characteristic. The streams contain cold and frequently rapid water, particularly in the west, and furnish the best conditions for various kinds of trout and salmon.

The most characteristic feature, however, is not the stream, but the lake fauna. Associated with these conditions is the great development of amphibious mammals now occupying the territory, such as the muskrat, mink, and beaver. The latter had a marked influence on the early exploration and settlement of the country. This vast area of ponds and swamps has led to the great abundance of pond-snails which characterize these northern lands. The fisheries of the Great Lakes, founded largely upon the abundance of lake trout and whitefish, show the present industrial importance of the lake fauna.

The land fauna, including the amphibious mammals, is characterized by its fur-bearing members, a factor primarily influenced by the long, severe winter, which favors the development of a heavy pelage or fur. The representative members of this class are the weasel (ermine), marten, mink, muskrat, beaver, and hare. To this list must be added other representative forms, such as the woodland caribou, elk, moose, Canada lynx, and the red squirrel.

In addition to the heavy clothing of fur of these animals, a further response to their environment is seen in the hibernating habit of some of the animals. Still others develop a white winter pelage or plumage, as in the case of the weasel, the ptarmigan, and the snowflake.

(e) **The barren ground and cold desert environment.** As the northern tree limit of the Canadian cone-bearing forest is approached, the trees gradually diminish in size, become stunted, and disappear from the uplands, and finally occur only along protected streams, and thus the barren ground conditions begin. The mosses, lichens, and low vegetation which farther south had occurred only in isolated patches upon the shallow soil, now expands. Only in Alaska do mountains interrupt the general monotony of the landscape. The region lies largely north of the annual isotherm of about 20° F., and the long winters are dark, and much of the short summers is perpetually lighted.

In general, the fauna is quite limited except near the coast, where food can be secured from the sea. Here sea-birds abound, and the polar bear and Eskimos find favorable conditions. Inland, vast herds of caribou pasture upon the "reindeer-moss" and other low vegetation, but all other forms of animal life are limited. Some characteristic animals are the arctic hare, arctic fox, and the musk-ox. During the summer, these barren grounds furnish breeding-places for numerous birds (some wading birds, the eider-duck, little auk, etc.), which migrate southward as the short summer fades away.

Some of these arctic animals are white in the winter only, as the arctic fox and hare, but the polar bear remains white throughout the year. It is also of interest to note the relative abundance of life near the coast, and its carnivorous character, as contrasted with its great decrease inland, and the dominance of herbivorous forms.

The larger part of this area was covered with ice in the glacial period, and consequently has been repopulated, largely from the south, since the ice melted.

This cold semi-desert is analogous to that found in the high mountain regions farther south. But these high mountain or alpine conditions are even more limited in extent than the barren grounds, and generally much isolated.

PART IV

THE OCEAN

CHAPTER XX

THE OCEAN AS A WHOLE

The oceans lie in the great depressions in the earth's surface (p. 5). These depressions are called *basins*, but they have little resemblance to the homely vessel which bears this name. If with a string four feet long as a radius, we draw on the blackboard an arc three feet long, it will represent about an eighth of a circle. This may be taken to represent the width of the Atlantic Ocean between the United States and Europe. If the top of the chalk line stands for the surface of the ocean, another line representing the bottom of the ocean could not well be drawn below it with a common crayon, without exaggerating the depth of the water.

Fig. 448 may help to give us some conception of the real shape of an ocean basin, which is, in general, convex upward.

The sea-level. The surface of the sea is very different from that of the land. The latter is uneven. while the former, except for the waves, seems very even. We speak of the surface of the sea as if it were level, but it is in reality a curved surface, and its curvature is nearly that of a sphere. somewhat flattened at the poles.

What the physical geography of the sea includes. The physical geography of the sea includes many things. Among them are (1) the distribution of its waters, (2) its depth at all points, (3) the topography of its bottom, (4) the composition of its water, (5) its color, (6) its temperature at the surface and beneath it, (7) its movements, (8) its life, and (9) the material of its bottom.

The physical geography of the sea has become known in various ways. The distribution of its waters was known as soon as the continents had been outlined. The composition of its waters is known by chemical analysis. Some of its movements, such as waves, may be seen and studied from the shore. Others, such as the currents (streams in the ocean), are less readily seen, but have become known (1) by their effects in changing the courses of sailing-vessels, (2) by the courses of objects floating in the water, (3) by their effects on temperature, and in some other ways.

The most that is known of the depth of the ocean, its temperature, its life, and the material and topography of its bottom, has become known through exploring expeditions which have been sent out from time to time to study these things. The expeditions which have done most have been fitted out by governments in some cases, and by societies or individuals in others. The greatest expedition of this sort was that of the Challenger, 1872–76, sent out by the British government. This vessel made explorations in the Atlantic, the Pacific, and the Southern oceans (Fig. 449). Many other smaller expeditions have made valuable contributions to our knowledge of the ocean.

Distribution of the ocean waters. The distribution of the ocean waters has been outlined in a general way in connection with the land (p. 6). The ocean encircles the earth in latitude 60° S., and the waters south of latitude 40° S. are sometimes called the Southern Ocean. From it the Atlantic, the Pacific, and the Indian oceans extend northward. In the northern hemisphere the land makes an almost complete circuit in latitude 60° to 70°, whence it extends southward in two great arms. North of latitude 70° or so, lies the Arctic Ocean.

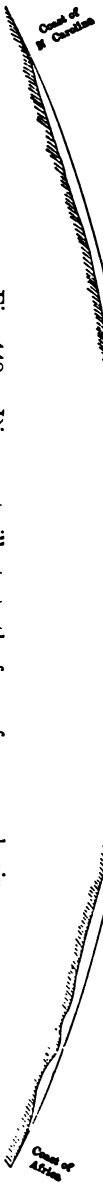

Fig. 448.—Diagram to illustrate the form of an ocean basin.

The Arctic Ocean is a little more than one-fortieth of the area of the sea, the Indian Ocean about one-eighth, the Southern Ocean one-fourth, the Atlantic one-fifth, and the Pacific three-eighths.

Depth. The average depth of the oceans is about two and one-half miles, or between 12,000 and 13,000 feet. The Pacific is the deepest, and the greatest known depth of ocean water is nearly six miles, or a trifle more than the height of the highest mountain above the sea. There are many places where the depth of the ocean exceeds four miles, and the area of very deep water is much greater than the area of very high land. The areas which are far below the average depth of the ocean are often known as *deeps*.

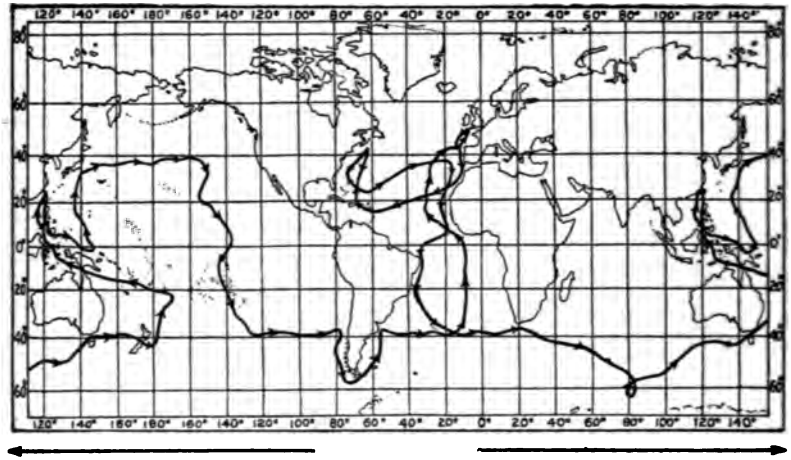

Fig. 449.—The course of H. M. S. Challenger, shown by the heavy line on oceanic areas.

The greatest known depth of water, 31,614 feet, is in the Northern Pacific, near the Ladrone Islands. Another area of almost equal depth (30,930 feet) is the Aldrich Deep northeast of New Zealand. A depth of nearly 28,000 feet is found in the Tuscarora Deep east of Japan, and a depth of about 25,000 feet (nearly 5 miles) off the coast of Chile, in latitude 24°-25° S.

Most of these great depths are in the western part of the Pacific. Some of them are close to continents, and the others are in regions of abundant islands, where the surrounding water is not very deep. In all cases the slopes down to these great depths are steep, and in all cases the deeps are longest in a direction parallel to the nearest coasts, or to adjacent ridges beneath the water, or to ridges the crests of which rise into islands.

The greatest depth of water in the Atlantic is north of Porto Rico in the Blake Deep (lat. 20° N.; long. 65°–68°), where a depth of 27,366 feet is known. This deep, like those of the Pacific, is long and narrow, has steep slopes, and is parallel to the great ridge of which Porto Rico is a part. In few other places in the Atlantic does the depth reach 20,000 feet.

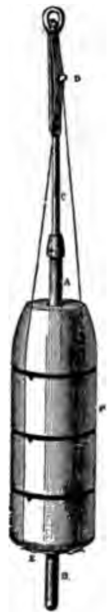

Fig. 450.—The sounding-line. (Challenger Report.)

The Indian Ocean is not known to have depths much exceeding 20,000 feet, and the deepest known place in the Southern Ocean is still less.

The depth of the ocean is known by *soundings*. Soundings are made from ships, by reeling out a heavy metallic weight held by a fine steel wire. The ball is so fastened to the line as to be set free when it reaches the bottom (Fig. 450), for it is much simpler to leave it at the bottom than to draw it up again. A sounding of 3,000 fathoms may be made in about an hour. (Why not use a rope, instead of a wire, in sounding?)

There is a common notion that the deeper waters of the sea are so dense that weights will not sink, and that sounding in the deep sea is difficult on this account. This is not correct. The water in the deepest part of the ocean is but a little heavier than that at the surface. It is difficult to make deep soundings, but the cause of the difficulty is not the great density of the deep water.

Volume. The average depth and the area of the oceans being known, the volume of water which they contain may be calculated. It is nearly fifteen times the volume of land. If all the material of the land were carried to the sea and deposited in its basin, it would raise the level of the water about 650 feet. If the surface of the lithosphere were brought to a common level by planing down all elevations and building up the deep parts of the ocean basins, the ocean water would cover the whole of the earth to a depth of about 9,000 feet, or nearly two miles.

Mass. The mass (weight) of the sea is only about five times the mass of the land above the sea, for water is only about one-third as heavy as an equal volume of rock. The weight of the sea-water is about 265 times the weight of the air which surrounds it, and about $\frac{1}{4500}$ that of the solid part of the earth.

Topography of the bottom. The larger part of the sea bottom is nearly flat, and is therefore very unlike the land. The surface of the land is made rough in various ways, but especially by running water; but rivers do not flow on the bottom of the sea, and the difference between the topography of the sea bottom and that of the land is due largely to their absence.

In spite of the general flatness of the sea bottom, its relief is not less than that of the land. The irregularities of its bottom are of several types. These are (1) *volcanic cones,* often built up from the bottom of the deep sea to the surface of the water, and even far above it (p. 250); (2) *steep slopes or scarps,* such as those where the continental platforms slope down to the deep sea basins, and such as those about some of the pronounced deeps; (3) *valley-like depressions,* especially on the continental shelves; (4) great *ridges* somewhat like the mountain ridges of the land; and (5) *broad, plateau-like swells,* much above their surroundings, and over which the water is not very deep.

1. Volcanic cones are more numerous in the Pacific Ocean than elsewhere, and more numerous in its deeper western part than in its shallower eastern part. They seem to rise abruptly, but their slopes are much less steep than they seem. The upper parts of volcanic islands rarely have a slope of more than 30°, and their lower parts rarely more than 6° to 10°. Below the sea the slope is still gentler, rarely more than 3°, or 1 mile in 20. Figs. 451, 452, and 453 show slopes corresponding to 1 mile in 5, 1 in 10, and 1 in 20.

2. Though the slopes of the bottom at the edges of the continental shelves and above the deeps are steep, as slopes in the ocean bottom go, they are much less steep than many slopes on the land. A slope of 1 mile in 8 is rare, and a slope of 1 mile in 20 (Fig. 453) can hardly be said to be common. Such a slope would make a steep railway grade. Slopes of 1 in 60 are steeper than the average slope at the edges of the continental shelves. So far as steepness goes, railway trains could be run without much grading up most of the slopes on the outer edges of the continental shelves.

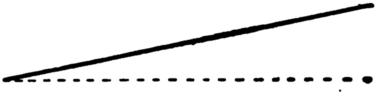

Fig. 451.

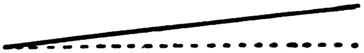

Fig. 452.

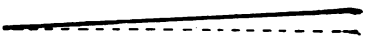

Fig. 453.

Fig. 451.—Diagram illustrating a slope corresponding to 1:5.
Fig. 452.—Diagram illustrating a slope corresponding to 1:10.
Fig. 453.—Diagram illustrating a slope corresponding to 1:20.

In rare cases, slopes which would look steep, even on land, are found on the sea bottom. Thus in the Mediterranean Sea a difference of 1,500 feet was once found between the soundings taken from the bow and stern of a vessel, soon after a violent earthquake. Such slopes or scarps are doubtless the result of faulting (Fig. 323).

3. On many continental shelves there are valleys which are much like river valleys. Many of them are continuations of valleys on land. Thus the Hudson, the Delaware, the Susquehanna, the St. Lawrence, and other valleys are continued out under the sea. The valley of the Hudson extends out to the edge of the continental shelf. It has a maximum depth of 2,400 feet below its surroundings, and 2,844 feet below sea-level. The submerged parts of the Delaware and the Susquehanna valleys are less than 100 feet below their surroundings on the continental shelf.

Other submerged valleys, as some of those on the Pacific coast of the United States, do not seem to be the continuations of existing land valleys. Some of the submerged valleys are hundreds of miles long and thousands of feet (maximum) deep. They were probably formed by rivers when the areas where they occur were land.

4. Examples of mountain-like swells are furnished by Cuba and the adjacent islands, which are really the crests of a great mountain system rising from deep water.

5. An example of the plateau type of elevation is the *Dolphin Ridge* of the Atlantic (Fig. 454). This broad, low swell extends to latitude 40° S., and divides the basin of the Atlantic into two troughs, the one to the east and the other to the west, where the water is much deeper than over the ridge itself. In the Southern Pacific, volcanic islands often rise from submerged plateaus.

From the foregoing it will be seen that great irregularities are found on the sea bottom as on the land, but that the many small unevennesses of the land, especially those made by running water, wind, glaciers, etc., do not appear on the ocean's bed, except in very shallow water.

COMPOSITION OF SEA-WATER

One hundred pounds of sea-water contains nearly three and one-half (3.44) pounds of dissolved mineral matter. Of this, common salt makes up more than three-fourths (nearly 78%), but many other substances occur in very small quantities. These mineral matters in the sea-water make it a little heavier than fresh water.

If all the salts of the sea were taken out of solution and laid down as a layer of solid matter on the ocean bottom, they would make a layer about 175 feet thick. This volume of mineral matter would be equal to about one-fifth of all lands now above the sea.

Sources of mineral matter. Mineral matter dissolved in water is being carried to the sea by rivers all the time. Rivers have brought the sea most of its mineral matter, though some of it may have been dissolved from the rocks beneath the sea, or about its shores. The mineral matter carried in solution to the sea by rivers in a year would make nearly half a cubic mile.

The minerals which are most plentiful in the sea are not those which are most common in the rocks of the land. Those minerals of the land which are most easily dissolved get into rivers, and thence to the sea, in greater quantity than those which are less

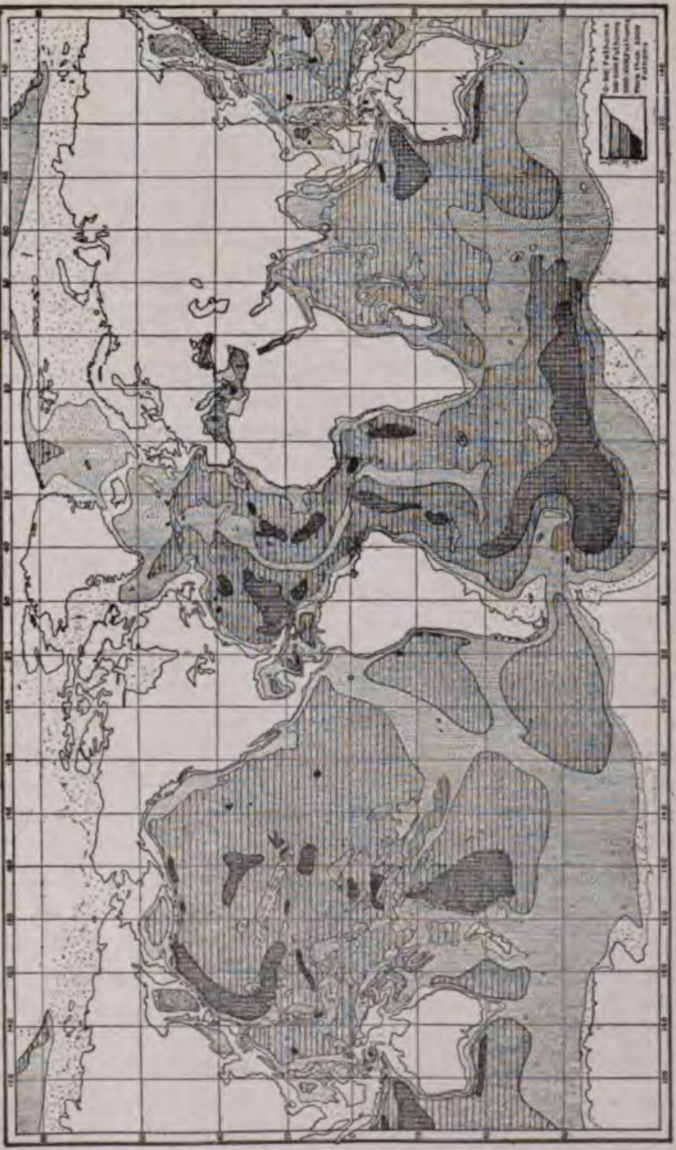

Fig. 454.—Chart showing depths of the ocean. (After Sir John Murray.)

soluble. But some of the minerals in the sea-water, such as salt, do not exist in the common rocks of the land. They are made by the union of a substance in the rocks with a gas in the air or water. Granite, for example, has no salt, but it contains sodium, which is one of the elements of salt. When the sodium unites with chlorine (a gas), the result is salt. It takes much granite to yield a little salt.

Withdrawal of mineral matter from the sea. Of the mineral matters carried to the sea by rivers, calcium carbonate, the substance of which most shells are made, is the most important. The amount of this substance in river water is nearly as great as that of all others. Common salt is present in river water, but its amount is too small to be tasted; yet the amount of salt in the sea-water is more than 200 times that of the calcium carbonate. The reason is that the calcium carbonate is being taken out of the water all the time by the animals which live there, to make shells, coral, etc., while most of the salt which is carried to the sea, stays in the water, and this seems to have been true for millions and millions of years.

Gases in sea-water. The sea-water contains dissolved gases, also. The most abundant are those of the air, namely nitrogen, oxygen, and carbon dioxide. The amount of oxygen dissolved in the ocean is rather more than $\frac{1}{300}$ of that in the air; the amount of nitrogen about $\frac{1}{100}$ that of the air, while the amount of carbon dioxide in the sea is about eighteen times that in the air.

Much of the gas in the ocean was dissolved from the atmosphere. After being taken into solution at the surface, the gases are distributed through the whole ocean, partly by the movements of the water, and partly in other ways. The carbon dioxide of the sea does not all come from the air. Some of it is breathed out into the sea-water by the animals which live there, and some of it comes from the many volcanic vents under the sea.

The oxygen of the water is being used all the time by the animals which live in the sea, and its supply is being renewed all the time by solution from the air. Animals and plants do not use the nitrogen dissolved in the water, and the same nitrogen probably stays there from year to year and from age to age. The carbon dioxide is being used all the time by the plants of the sea, and some of it is constantly escaping into the air.

Salinity, density, and movement. Some parts of the sea are more salt than others. There are several reasons for this. (1) The salt is left behind when ocean water evaporates. Since evaporation is more rapid in some places than in others, the water becomes more salty where evaporation is great, as generally where the climate is hot. (2) Where the amount of rainfall is great, the water is freshened. (3) Where rivers enter the sea, they bring in fresh water. In all the above ways the saltness of the sea-water at the top of the ocean is being changed all the time.

The more salt there is in water, the heavier it is. Every change in its saltness changes its density, and unequal density causes movement. When the surface water becomes more dense than that beneath, it sinks, and the lighter water comes in over it from all sides. When the surface water of one place becomes less dense (fresher) than the water about it, the lighter water spreads out on the surface, for the same reason that oil spreads on water. Since variations in the saltness are being produced all the time, motion due to unequal density is constant. Movements brought about in this way are usually very slow, and may be called *creep*.

Salinity and color. The sea is generally blue or green, but its color varies from place to place and from time to time. The blue is deeper where the amount of salt is great. Thus inland seas, such as the Mediterranean, which are more salty than the open ocean, are of deeper blue. The cold and less salty waters of high latitudes are often distinctly green. Many of the variations of color are due to the tiny particles of solid matter in suspension in the water. Microscopic animals and plants, and the sediment washed or blown out from the land, or furnished by volcanoes beneath the sea, all help to give the sea-water of different places its different colors.

THE TEMPERATURE OF THE SEA

Temperature of the surface. The surface of the ocean, like that of the land, is warmer near the equator and cooler the poles (Pl. XXII). Near the equator its temperature is about 80° F.; near the poles, where not frozen, it is about 28° F. When the temperature sinks below the latter figure, the sea-water freezes, and the surface of the ice may become as cold as the air above it; but the temperature of the water just beneath the ice is never much below 28° F. The decrease of temperature toward the poles is by no means regular, as shown by the isothermal charts. In Pls. XXII–XXIV, for example, the isothermal lines over the ocean are not parallel with the parallels of latitude.

In the open ocean, ocean currents make the isotherms depart from the parallels. Some of these currents are of cold water flowing into warmer water. These are *cold currents.* Some of them are of warm water flowing into cooler water. These are *warm currents.* A cold current turns an isotherm toward the equator, and a warm current turns it toward the pole. Pl. XXIII shows the effect of a warm current in the North Atlantic on the position of the isotherms.

There are other reasons why the surface water of the ocean does not get colder steadily from equator to poles. Rivers entering the sea are often warmer than the sea in summer, and colder in winter. They therefore help to make surface temperatures unequal. Enclosed or partly enclosed arms of the sea in low latitudes are warmer than the open ocean in the same latitude. The highest temperatures of the sea are found in such situations. The surface temperature of the Red Sea is sometimes 90° or even 100° F.

Temperature and movement. Water expands on being warmed. Warm water is therefore lighter than cold water, if both are equally salt. It follows that unequal surface temperatures cause movement of the surface waters. The movements due to this cause are always slow, but since the surface temperature is kept unequal all the time by unequal heating, by the inflow of rivers, and by melting ice, there must be constant though slow movement of the surface waters, because of differences of temperature.

The surface of the sea is cooler at night than during the day, and cooler in winter than in summer; but the daily and the seasonal changes are both much less than those on the land in the same latitude.

Temperature beneath the surface. The water becomes cooler with increasing depth, except where the surface is at or near the freezing-point. Even where the surface water is warmest, the temperature at a depth of a few hundred fathoms is below 40° F., and that at the bottom still colder. The following table shows the average temperature of the sea at various depths:

Depth	Average Temperature
600 feet	60.7°
1,200 feet	50.0°
3,000 feet	40.1°
6,000 feet	36.5°
13,200 feet	35.2°

It is estimated that not more than one-fifth of the water of the ocean has a temperature as high as 40° F., while its average temperature is probably below 39° F. At the bottom of the deep sea the temperature is generally below 35° F. The only parts of the ocean bottom where the temperature is as high as 40° F. are the areas of shallow water, and the enclosed seas of relatively low latitudes.

The temperatures of the deeper parts of enclosed seas in low latitudes are very different from the temperatures of the deeper parts of the open sea. The temperature of the Red Sea falls from 90° F. or more, at the surface, to 70° F. at a depth of 1,200 feet, and then remains nearly the same to the bottom at 3,600 feet. In the Mediterranean the temperature falls from about 75° F. at the surface to 55° F. at a depth of 750 feet, and then remains about the same to the bottom at 13,000 feet, while the temperature of the ocean outside falls to 37° F. The higher temperature of the deep waters of these enclosed seas is due to the sunken barriers which partially shut them off from the ocean, and do not allow the colder and denser waters outside to flow in and displace the warmer and lighter waters below the top of the barrier (Fig. 455). The temperature of the bottom of enclosed seas in some latitudes is about the same as the temperature of the sea-water at the level corresponding to the top of the barrier.

The great body of the sea-water is cold because the cold waters of the surface always tend to sink. The supply of ice-water from the ice-caps of the polar regions is very great, and though it is fresh, and therefore lighter than sea-water at the outset, it soon becomes salt by mixing with salt water. This enormous supply of ice-water is the great cause of the low average temperature of the sea.

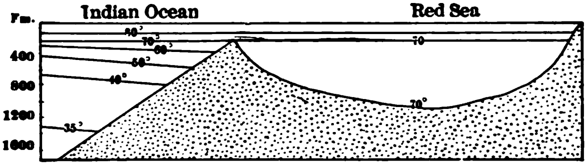

Fig. 455.—Diagrammatic section of Red Sea and the adjacent part of the Indian Ocean, to illustrate the effect of a barrier on the temperature of the waters. The temperature is expressed in degrees Fahrenheit. The numbers at the left show depth in fathoms. Vertical scale exaggerated.

The temperature of the water below the surface is known by a thermometer made for this especial purpose. Its chief peculiarities are (1) that it will stand the great pressure of deep water, and (2) that it will record the temperature of any depth. A good thermometer of this sort was not invented until 1869, just before the start of the Challenger expedition.

The ice of the sea has been referred to in other connections (p. 152). Attention may here be recalled to the fact that sea-water, unlike fresh water (p. 149), becomes denser as it becomes colder, until it freezes. As it freezes it expands, and so becomes lighter than the water beneath, and remains on the surface. The ice on the surface protects the water beneath from the chilling effects of the cold air, so that even in polar regions it freezes but a few feet down. The movement of floating ice is controlled partly by the winds, and partly by the movements of the water in which the ice floats.

THE MOVEMENTS OF SEA-WATER

Causes

We have seen that differences in saltness and in temperature make water unequal in density, and that differences in density produce a slow circulation of the waters of the sea. There are other causes, also, which produce movement. Among them are (1) differences of level, (2) the winds, and (3) the attraction of the moon and the sun. There are also (4) occasional causes, such as earthquakes and volcanic explosions, which produce sudden and sometimes disastrous movements.

Movements due to the inequalities of level. The inequalities of level which produce movement are brought about chiefly by (1) the discharge of rivers, which raises the surface of the sea at the point of inflow; (2) winds, which pile up the waters along the shores against which they blow; (3) unequal rainfall, which raises the surface most where most falls; and (4) unequal evaporation, which lowers the surface most where it is greatest.

All inequalities of level of the surface cause movements of its waters. The movements due to unequal rainfall and evaporation are generally too slight to be seen or felt. Those caused by the inflow of rivers and by the wind are greater. Thus, beyond the mouth of a great river like the Amazon, the movement is often distinct for many miles, and waters are often piled up against a shore by winds, to such an extent as to be readily seen. During a storm on the coast of India in 1864, the water was raised 24 feet at Calcutta, drowning 48,000 people. The raising of the surface of the water caused most of the destruction in the storm at Galveston, already referred to (p. 423). When the water level has been raised along a coast by the wind, it will settle back after the wind goes down. Since the causes producing differences of level are always in operation, movements due to these differences are always taking place.

Movements due to the wind. Winds produce temporary differences of level, as just noted, but they also affect the water in other ways. They produce waves, and they drag the water along beneath themselves when they blow over its surface. If a floating net is dragged over the water, the water beneath it moves, and that immediately beneath the net moves faster than that farther down. The air acts in a similar way. When it moves over water, it drags the surface water along with it, sometimes fast enough so that the movement may be seen or felt. This movement is sometimes called *drift*.

Since winds are always blowing, the movements which they cause are always taking place. When winds have a constant direction, as in the zone of trades, there is always movement of the surface water in the same direction. A steady movement in one direction will always cause a return movement, thus producing a *circulation* of the sea-water.

Movements due to the sun and moon. Bodies attract each other in proportion to their masses, and inversely as the squares of their distances. That is, a body which weighs twice as much as another has twice the attractive force *at the same distance.* If one of two bodies of the same mass (or weight) is twice as far from a third body as the other is, their attractive forces on the third are to each other as 1: 4.

The side of the earth towards the moon is nearer the moon than the center of the earth is, and so is attracted by the moon more strongly than the center. The opposite side is attracted less strongly than the center, and these differences of attraction disturb the waters of the earth. The attraction of the sun produces similar effects. The resulting movements of the sea are the *tides.*

Movements due to occasional causes. The occasional causes of movement (p. 288) sometimes make violent waves which last but a short time. Illustrations of their nature and effects have already been given in connection with earthquakes and volcanoes. Faulting and landslides along shore, as well as earthquakes and volcanoes, may cause movements of the water.

TYPES OF MOVEMENT

The movements which result from the foregoing causes are (1) *waves,* with the *undertow* and *shore currents* which they produce, (2) *ocean currents,* (3) *drift,* or currents which are feeble and not well marked, (4) *tides,* and (5) what we may call *creep* (p. 495).

Waves

The work of waves and their effects on coast lines have been outlined already (p. 226). It may be added here that the waves of the sea make much land by deposition, and destroy more by erosion. If nothing happened to prevent, the sea would finally destroy all land by the continued cutting of its waves along the shores.

Since the water in waves does not commonly move forward, waves do not produce a general circulation of ocean water.

Currents and Drifts

There are more or less distinct streams of water, or *currents*, in various parts of the ocean. This was first known by the effect of the moving water on the course of sailing-vessels. It was later proved in various other ways, as by following the course of floating objects set adrift for this purpose. One form of float consists of two bottles tied together with a string about twenty-five feet long. The lower bottle, filled with water and left uncorked, tends to sink. Into the other bottle a little sand is put — enough so that it will just float, and buoy up the lower bottle. The reason for the bottle below the surface is the same as the reason for weighting the upper bottle as much as possible, without sinking it; namely, to prevent the float from being drifted about by the wind. A note is put in the bottle with the sand, telling the exact position of the ship at the time the float is thrown overboard. It also asks the finder to write the time and place of finding the bottle upon the same slip of paper, and then to mail it to the sender, whose address is given. When this note is in the bottle, it is tightly corked, and the float is thrown overboard.

The Prince of Monaco set more than 1,600 floats adrift in the North Atlantic during the years 1885, 1886, and 1887. Within four years 227 of the notes had been returned to him. Since he knew where they started and where they landed, he was able to make a chart of the currents of that ocean.

The best known currents in the ocean are at its surface, and they extend down to depths of several hundred feet. Ocean currents are not so easily seen as the currents of running water on the land, because their waters flow through a liquid, while rivers flow in a channel of solid material. A slow current, which is not very distinct, is often called *drift*. According to this use of the term, a current may become a drift when it spreads out and becomes slow.

Fig. 456 shows the general course of movement of the surface waters of the seas. The figure represents a large part of the surface water as moving. There are westward movements near the equator in both the Atlantic and the Pacific oceans. These are the *equatorial currents* or *drifts*. In each ocean the drift is double, and a narrow *counter-current* or *drift* moves eastward between them. The equatorial drift of the Atlantic Ocean is divided into two parts as South America is approached, one part being turned to the southwest, and the other to the northwest, along the border of the continent. A part of the latter flows through the Caribbean Sea, and into the Gulf of Mexico. From this gulf a distinct current issues through the narrow passageway between Cuba and Florida. This is the *Gulf Stream*. It is fed partly by the water which enters the Gulf from the equatorial drift, and partly by the water which enters the Gulf from the land. The current issuing from the Gulf has a velocity of more than four miles per hour where it is swiftest.

North of the narrow passageway between Florida and Cuba, the Gulf Stream becomes wider and deeper, and as more water moves, the rate of movement becomes slower. In the open ocean the rate is perhaps no more than 10 to 15 miles per day. As the current becomes slow, its boundaries become less well defined, and it is recognized by its temperature, its color, its life, etc., more readily than by its motion.

As it flows northward, the Gulf Stream turns to the eastward (to the right). It crosses the Atlantic, approaching the coast of Europe in a latitude farther north than that where it leaves the coast of America. Here it divides and spreads out. Long before Europe is reached, the current has ceased to be a definite stream, and is rather a general wide-spread drift of water.

That part of the equatorial drift which is turned southward along the coast of South America follows the coast of that continent for a time, but soon turns to the left (Fig. 456).

The equatorial drifts of the Pacific follow similar courses. The part which turns north is known as the *Japan Current*. The Indian Ocean has a south equatorial drift only, and its course corresponds to that of the southern part of the equatorial *drifts* of the other oceans.

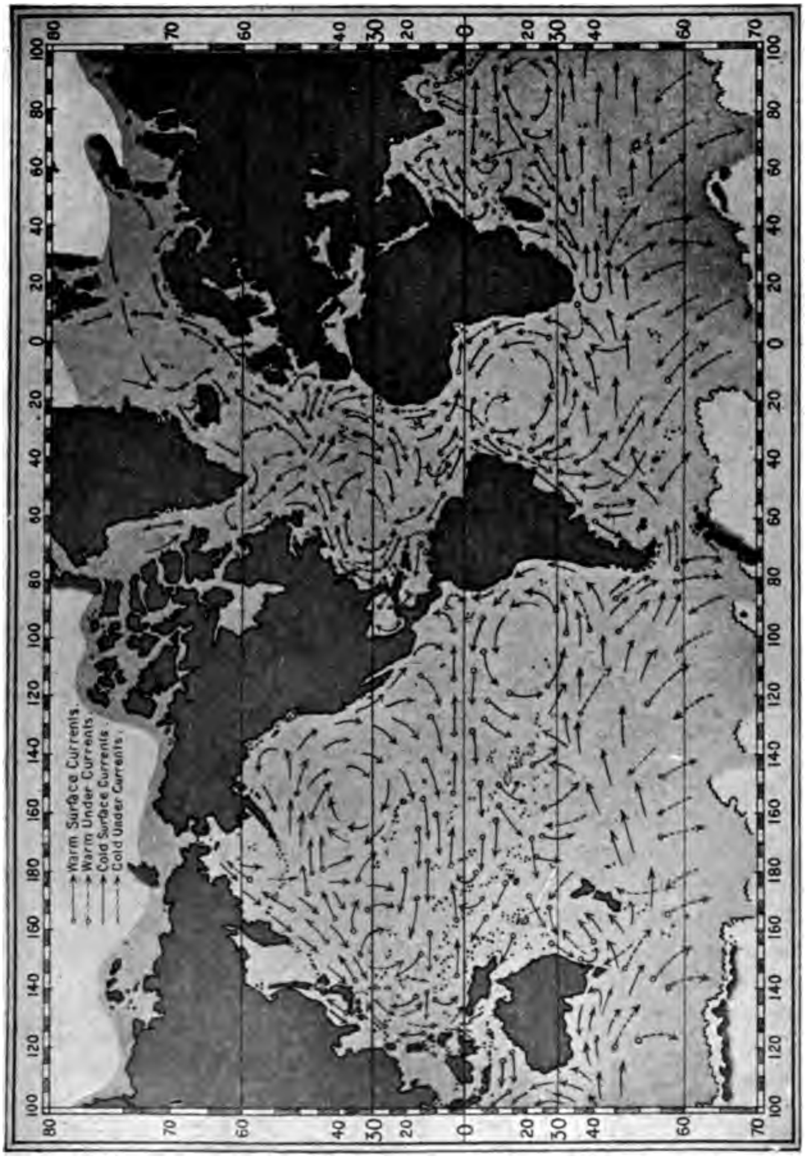

Fig. 456.—The courses of the ocean currents. (Wild.)

All currents moving toward the poles from the equatorial region are *warm currents*.

The poleward movement of warm waters makes a return equatorward movement necessary. The cold waters moving toward the equator are turned to the right in the northern hemisphere, and to the left in the southern. The result is to throw them to the eastern coasts of the continents, where they sometimes form distinct currents.

The equator-ward drifts start from latitudes where ice abounds. Their waters are very cold, but not so salt as most sea-water. As they move equator-ward, they become warmer and more salty, and they finally sink and continue their courses toward the equator beneath the surface. On the other hand, the poleward (warm) currents start in low latitudes as surface currents, kept at the surface by their high temperature, in spite of their slight excess of salt. In their poleward journey, they may sink beneath the cooler, fresher water, and continue as warm undercurrents. Both cold and warm undercurrents are known to exist.

Cause of ocean currents. It is now generally believed that the equatorial drifts are produced by the trade-winds. Outside the tropics the winds do not blow in one direction all the time, and so do not produce steady currents. But in regions of strong monsoon winds, as about India, the drift of the surface waters changes with the shifting winds (Figs. 394 and 396), thus showing that steady winds are able to produce movements of the water.

If the ocean covered all the earth, the westward drift of the equatorial waters, caused by the trade-winds, would go round and round the earth. But the continents prevent this, and where the waters of the equatorial drift reach their shores, they are turned from their westerly course to the north or south.

After the moving waters pass out of the zone of the trade-winds, their course is directed chiefly (1) by the shores, (2) by the prevailing winds, and (3) by the rotation of the earth. Their *courses* are therefore given them partly by the causes which *make* them, and partly by other causes which *direct* them.

Differences in temperatures may help in producing ocean currents. Such differences would not produce distinct currents;

but movements started by unequal temperatures may be concentrated and directed so as to strengthen the currents made by the winds.

Climatic effects of ocean currents. The ocean current itself does not warm or cool the land, but the air over a warm ocean current is heated by the water, and may then be carried over to the land. In middle latitudes, for example, the westerly winds carry the air warmed by the warm currents over to the coasts of the continents lying east of them. This makes the coasts on the east sides of the oceans, in the intermediate zones, warmer in winter than they would be otherwise, and gives them, at the same time, plenty of moisture. The winter temperature of the west coast of northern Europe (p. 456) is less severe than it would be but for the Gulf Stream.

The warm current in the North Pacific lessens the cold of winter along the northern part of the west coast of North America. Similar results would be found in the southern hemisphere, if there were land so situated as to feel the effects of the warm currents in the southern oceans.

Warm currents often give rise to fogs both at sea and on land. When the wind blows over a warm current, such as the Gulf Stream, it takes up a goodly supply of moisture. If it then blows over colder water, it is cooled, and some of its moisture is condensed, producing a fog. Fogs are common along the leeward side of the Gulf Stream, where the adjacent land or water is much cooler than the current itself. Fogs also occur wherever warm, moist air blows to cooler land. Fogs are more abundant about Newfoundland than farther south, because the difference in the temperature of the Gulf Stream and its surroundings is greater here than it is farther south.

Gradational effects of ocean currents. Currents have little effect on the ocean bottom, and almost none on coasts, because they rarely touch either. Where the water is shallow, however, as between Florida and Cuba, the Gulf Stream scours its bottom, somewhat as a great river might. Since ocean currents do little eroding, they carry but little sediment. The water of warm currents carries multitudes of plants and animals, many of which are very small, and these organisms, or their hard parts, such as shells, are scattered far and wide over the bottom of the ocean.

Historical suggestions. The currents of the Atlantic played an important part in the early history of America. The currents southwest from the Arctic made the early discovery of North America probable, after Iceland had been colonized by the Northmen. The south equatorial current carried the Portuguese, bound for India, in 1500, to the shores of South America.

Ocean currents were formerly of great importance in ocean travel, but since steamships have taken the place of sailing-vessels to a great extent, ocean currents are of less importance than formerly in directing the courses of ocean vessels.

Tides

Along most coasts, the ocean water rises and falls twice every day, or, more exactly, every 24 hours and 52 minutes. The rise and fall of the water are the *tides*. The tide rises for about six hours, when it is *high*, and then falls for about six hours, when it is *low*. In some cases the tide comes in as a series of waves, but this is not always the case. The rise and fall amount to several feet in most places. In bays which open broadly to the sea, but which are narrow at their heads, the range is sometimes 20 or 30 feet, and in rare cases, as in the Bay of Fundy, even 50 feet or more.

In many harbors, especially where the water is shallow, the rise and fall have an important effect on navigation. Vessels coming to such harbors at low tide must often wait until high tide before entering. Where the tide runs in among islands, or passes through narrow straits, it often causes distinct currents, or *tidal races*. They are sometimes so strong as to interfere with boats, especially small ones.

Tides are not felt in small lakes, and are feeble in large lakes, enclosed seas, and in all bodies of water connected with the open sea by a narrow passageway, such as the Mediterranean Sea and the Gulf of Mexico. Thus at Galveston, Texas, the range of the tide is less than one foot.

The tide sometimes runs up a broad open river. As it advances up the channel, its front may become a steep, wall-like wave called a *bore*. The bore is felt, for example, in the Severn River of England, in the Seine of France, in the Petit-Codiac of Canada, in the Hugli of India, and the Tsien-Tang-Kiang of China. In the last-named river the waves are sometimes 25 feet high, and disastrous to navigation. From the head of the Bay of Fundy the tide runs up the river 70 miles, as a bore, and is felt up the river to the point where the elevation of the river is 14 feet above the sea.

High tides are felt, though not as bores, up the Hudson River to Troy, where the range of the tide is more than two feet, and up the Delaware nearly to Trenton. The tide is felt up the estuary of the St. Lawrence 283 miles, nearly to Montreal.

The periodicity and the cause of tides. The moon rises and sets twenty-four hours and fifty-two minutes later each day than it did the day before. The time between two high tides or between two low tides is half this period. It appears to have been this fact which suggested that the tides were caused by the moon. It is at least two thousand years since the moon was first thought to be the cause of the tides, but it is only about two hundred years since Newton explained how the moon produces this result.

The law of attraction between bodies has already been stated (p. 500). Without attempting to give a full explanation of the tides, some of the essential principles involved may be understood.

If a weight is attached to a string and whirled, the weight tends to move forward in a straight line. It is prevented from doing so by the string which holds it in its circular path. The tendency of the weight to fly away from the circle in which the string holds it is often called *centrifugal force*. The pull of the string which holds the weight is a *centripetal force*. The string is affected by these two opposite and equal forces.

The motion of the moon about the earth is not unlike the motion of the weight at the end of the string. The earth and the moon attract each other, and would fall together but for the centrifugal force due to their motions. At the center of the earth, and at the center of the moon, the attraction between these bodies is exactly balanced by the centrifugal force due to their revolutions. The result is that neither falls toward the other. But on the side of the earth nearest the moon the attraction is stronger than at the center of the earth, and is greater than the centrifugal tendency. *The attraction of the moon therefore tends to make the earth bulge up on the side nearest the moon.* On the opposite side of the earth the attraction is weaker than at the center, and is less than the centrifugal force. Here, too, the earth tends to bulge out. The solid part of the earth is so rigid that it does not rise enough to be felt or seen. But the waters of the ocean move easily, and rise a little, and the rise takes place on opposite sides of the earth at the same time. This makes the *high tides.* Between the high tides the water sinks a little, making the *low tides.*

If all the earth were covered with ocean water, its surface would have two great tidal bulges, or waves (Fig. 457), at the same time. The highest part of one would be a point directly under the moon, and the highest point of the other would be opposite the first. Each wave would cover half the earth, and the borders of the two would meet in a great circle, where the surface of the water would be lowest.

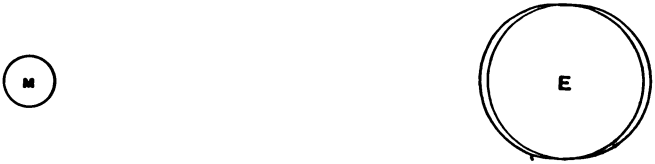

Fig. 457.—Diagram to show the tendency of the moon to raise the water on the side of the earth next to the moon, and on the opposite side at the same time, forming two high tides. M = moon, and E = earth.

The moon tends to hold one high tide under itself while the other tends to stay opposite the first, and the rotation of the earth carries each place out from under the position where the tide is high. Rotation tends to carry the high tides on beyond the place where the moon would make them. The moon tends to hold them back, and so they seem to travel about the surface of the earth in a direction opposed to its rotation.

The two high tides should be 180° apart. If the rotation of the earth were the only thing which determined the period of the tides, high tide at any place should come every 12 hours. The longer period (12 hrs. 26 min.) is due to the fact that the moon moves forward in its orbit about the earth (Fig. 458), so that it

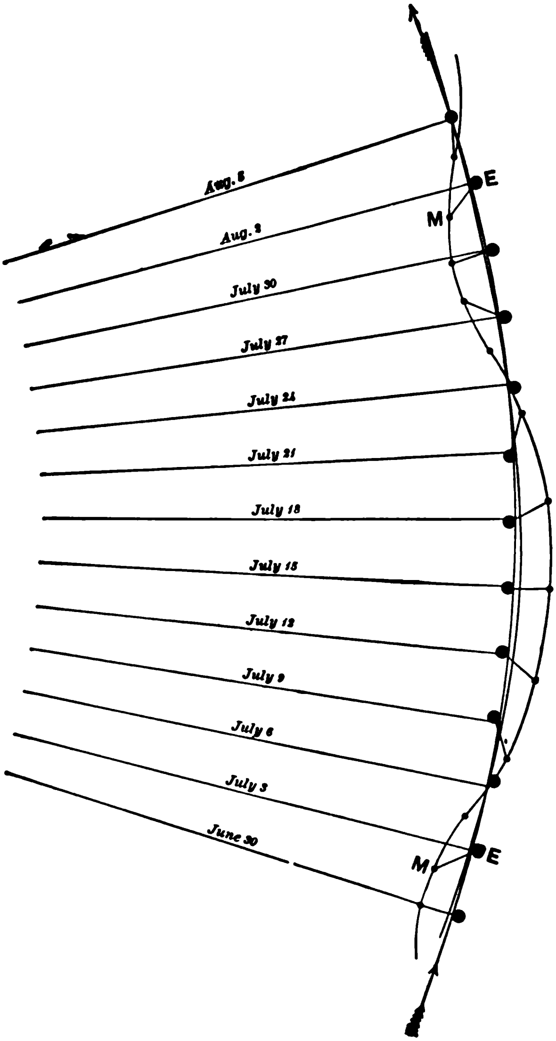

Fig. 458.—Diagram illustrating the motion of the moon about the earth. The larger circles (or dots) represent the earth, and the smaller the moon on the line which represents its orbit.

takes 24 hours and 52 minutes for a given place to have the same relation to the moon that it had the day before (Fig. 459).

The movement of the tides is not so simple as the outline above would imply. Many things interfere. The continents stop the advance of the tidal waves, and they travel more slowly in shallow than in deep water. Since tides are retarded most near continents and islands, their advance is here most irregular.

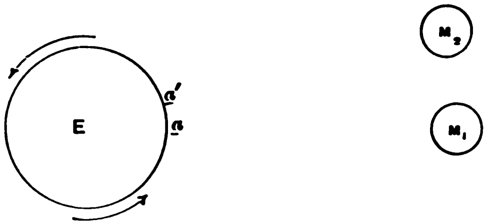

Fig. 459.—Diagram to show why it takes nearly 25 hours for a given place to come twice into the same relation to the moon. The earth rotates in 24 hours, and at the end of that period, a point, as *a*, has made the circuit. But the moon, which was at M_1 at the beginning, has advanced to M_2, so that *a* must move on to *a'*, before it has the same relation to the moon that it had the day before.

Solar tides. The sun also attracts the earth, and tends to cause tides. If there were no moon we should still have tides produced by the sun. The sun is very much farther from the earth (about 93,000,000 miles) than the moon is; but because of its great size it attracts the earth much more strongly than the moon does. Yet the tides produced by the sun are less than half as high as those produced by the moon. The reason is that the *difference* between the attraction of the sun for the center, and for the side of the earth nearest it or farthest from it, is much less than the *difference* between the attractions of the moon for the same points. The tides which are actually felt on the earth are the result of the influence of the moon and the sun; but since the moon's tides are much the stronger, the sun's tides merely modify them. The sun strengthens the tides when sun and moon work together, and weakens them when they work against each other.

Spring tides and neap tides. When the sun and the moon stand n the relation to each other and to the earth shown in Fig. 460

(*new moon*), each tends to make high tides at *A* and at *B*. When the relations are those shown in Fig. 461 (*full moon*), the result is the same. At these times, and each occurs once a month, the high tides are higher and the low tides lower than at other times. The tides of such times are called *spring tides*. Spring tides have no relation to the spring season.

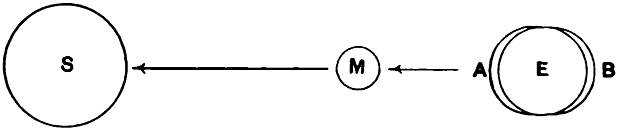

Fig. 460.—Diagram to show the relative positions of the earth, moon, and sun, at the time of new moon (=spring tide).

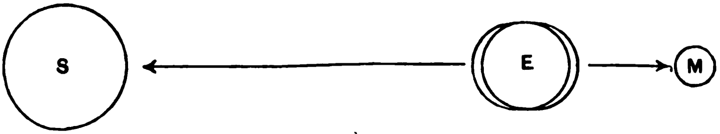

Fig. 461.—Diagram to show the relative positions of the earth, moon, and sun, at the time of full moon (=spring tide).

When the earth, moon, and sun have the relative positions shown in Fig. 462, and this occurs twice each month, the tidal influences of the sun and the moon are opposed to each other, and the result is that the high tides are not so high, or the low tides so low, as under other conditions. The tides of such times are known as *neap tides*.

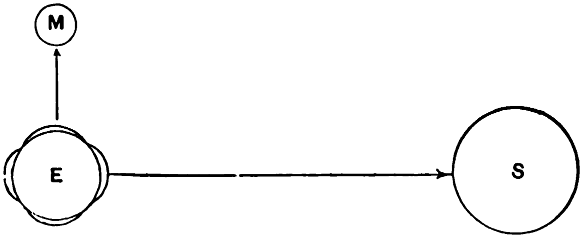

Fig. 462.—Diagram showing the tendency of the sun and moon to produce tides on opposite parts of the earth at the time of the quadrature, that is at a time half-way between new moon and full moon, or half-way between full moon and new moon.

Other variations in the height of high tides. There are several other causes of variation in the height of high tides. One of these causes shows itself daily, one monthly, and one yearly.

The two successive high tides of a given place are often of unequal height. If the high tide on one side of the earth is highest at *A*, Fig. 463, the highest point in the high tide on the opposite side would be at *B*, if the ocean covered the whole earth, and were of the same depth everywhere. From *A* on the one side, and from *B* on the other, the height of the high tide becomes less in all directions. The point *A′* has high tide at the same time that *A* and *B* have, but the tide at *A′* is not so high as that at *A*. Twelve hours and twenty-six minutes later, point *A* will have the same position relative so the moon that *A′* now has, because of the rotation of the earth and the revolution of the moon. The high tide which will occur at *A* when this point shall have reached the position *A′* will not be so high as that which it had when in the position *A*. The high tide which the point *A′* will have when it reaches the position *A*, will be higher than its preceding high tide. The amount of daily variation due to this cause is sometimes several feet. It would not occur when the moon is vertical at the equator, for then all points on the same parallel stand in the same relation to the highest part of the tidal wave.

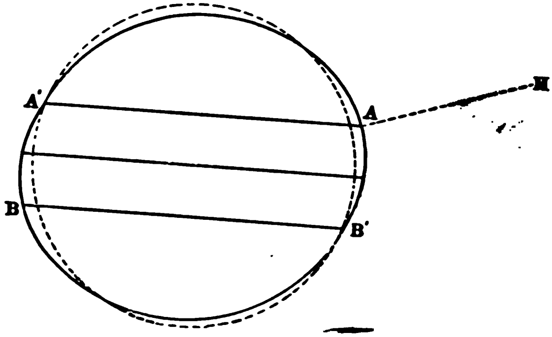

Fig. 463.—Diagram showing why successive high tides are often unequal.

There is a slight variation in the height of the high tides, due to the monthly variation in the distance of the moon from the earth.

The distance of the earth from the sun also varies during each year, and this variation has a slight effect on the height of the tides.

Cotidal lines. A line drawn on the surface of the ocean connecting all points which have the same high tide at the same time, is a *cotidal line*. A line connecting points having the same low tide at the same time is also a cotidal line. If the ocean had the same depth everywhere, and covered the whole earth, the cotidal lines would be great circles. But the continents and the shallow waters, and the islands and the straits, make them very irregular. The tide runs ahead where the water is deep, and lags where it is shallow. Cotidal lines are therefore very irregular.

Rate of movement. The tide should move forward from east to west, so as to complete a circuit in 24 hours and 52 minutes. This would give it great velocity in low latitudes — a velocity nearly equal to that of the rotation of the earth. This velocity is nearly reached in the deep and open sea, but nowhere else.

Effects of tides on shores. Since tides commonly rise in a series of waves, they affect shores much as wind waves do. Tides also produce currents (races) among islands, and through straits, and these currents are sometimes effective agents of erosion. Tidal *scour* often keeps waterways (thorofares) open through tidal marshes which the tide enters from bays. Illustrations are found on the coast of New Jersey (Fig. 272). Tidal scour also sometimes maintains deep waterways in bays, to the great advantage of navigation.

THE LIFE OF THE SEA

Animals and plants abound at and near the surface of the sea, and at the bottom where the water is shallow. If a bucket of water be dipped up from the surface of the ocean almost anywhere, it will be found to contain hundreds or even thousands of minute plants and animals, though most of them are too small to be seen without a microscope. Living things are present, but not in great numbers, at the bottom of the deep sea; but in the water between the uppermost 100 fathoms and the bottom, animals and plants are nearly absent. It has been estimated that the life of the sea exceeds that of the land, square mile for square mile, but there is no one level in the sea where life is so abundant as on the fertile parts of the land.

The distribution of plants in the sea is somewhat different from the distribution of animals. Plants are plentiful at the surface nearly everywhere, and at the bottom, down to the depth of about 50 fathoms. They occur sparingly down to depths of about 200 fathoms; but below some such depth they are absent, perhaps because of the darkness. Animals abound down to greater depths. They are also found, though not in great abundance, over the whole of the ocean's bed.

The temperature and the depth of the water influence the distribution of the different kinds of plants and animals in the sea. The clearness of the water, its saltness, and its quietness or roughness also affect the life.

The ways in which most of these factors influence the distribution of life will be readily understood. The depth of the water affects the distribution of those plants and animals which live on the bottom; but it has little effect on those which float or swim near the surface. The most important influence of depth appears to be in connection with the light, and with oxygen. Animals cannot see much at a depth of more than 50 fathoms or so, though a little light penetrates to greater depths. In the great body of the ocean, darkness reigns, and green plants, which depend directly on sunlight, cannot live in darkness. At the bottom of the deep sea the water is not stirred, and any oxygen it contains must pass down from the surface after being dissolved there. As it is used up by the animals at the bottom, the supply is renewed very slowly, chiefly by diffusion from above.

The pressure of the water at the bottom of the ocean is very great, but the animals living there can stand it, because their bodies are full of liquids under the same pressure, and these great pressures within their bodies balance the great pressures without. If an animal from the bottom of the deep sea were brought suddenly to the surface it would explode, because the pressure without is greatly decreased, while the pressure within remains great. Animals raised from the deep sea sometimes explode at the surface even when the raising is slow.

Some of the deep-sea animals are very unlike those of shallow water. Some are blind, but some have eyes, and this means, probably, that they see. Since sunlight cannot reach down so far, it has been thought that the phosphorescence of the animals themselves may supply the light.

Some animals, such as the polyps which make coral, live only in warm regions where the water is shallow and clear, with neither excess nor shortage of salt. Others, such as narwhals, seals, etc., are found only in cold waters. Still others are found in both warm and cold waters.

The life of the sea is in strong contrast in many ways with that of the land. Thus most plants with which we are familiar on land are fixed in position, while many of the plants of the sea float. Most animals on the land are free to move about, while many of those in the sea, such as coral polyps, barnacles, etc., are fixed through most of their lives. Many which are not fixed move about but little, either lying on the bottom or burrowing into it. Some, on the other hand, as many of those in the surface waters (*pelagic* life), appear to be always moving.

All the great groups of animal life are represented in the sea-water. Even warm-blooded mammals (whales, narwhals, seals, walruses, etc.) abound in the frigid waters, among icebergs and ice-floes. Some of these animals, like the seals and walruses, do not spend all their time in the water, but frequently crawl up on the ice. From this highest class of animals (mammals) down to the lowest, all important groups are represented in the sea, though no birds spend all their time in the water. The varieties of plant life are many, but the forms we are most familiar with on land, are wanting.

Not only are there many varieties of marine plants and animals, but the largest living animals (*whales*) live in the sea. Many of the sea plants, too, are of great size. Some seaweeds are six inches in diameter, and some have a length greater than that of the tallest trees. They are, however, not so bulky as large trees, and the amount of solid matter which the largest seaweed contains is far less than that of the largest tree. This would be seen if the large seaweeds were allowed to dry.

The life of the sea is important in many ways. Many of the animals, such as fish, oysters, clams, crabs, lobsters, etc., are used for food. The total value of food products derived from the sea is probably not less than $500,000,000 per year. Other animals furnish other articles of commerce. For example, the seal furnishes fur and oil; the whale, oil and whalebone; the hide of the walrus makes exceptionally strong leather. Coral and sponges, the products of animal life, are also articles of commerce.

Many of the animals of the sea have shells or other hard parts. These hard parts accumulate on the bottom of the sea when the animals are through with them, and this is one source of the sediments of the sea bottom. If the shells, etc., get together in great beds without much mud, sand, etc., they may in time be cemented together, forming solid rock, called *limestone.* Most of the limestone now found on land was formed in this way beneath the sea, when the sea covered parts of the present continents. The animals which make the heavier shells (or other secretions of calcium carbonate) live chiefly in shallow water, and the seas in which the limestones of the land were formed were generally, if not always, shallow.

Coral reefs. Coral reefs are of so much interest and importance that they deserve a special word. The little animals (called *polyps*) which secrete the coral live (1) where the water is 120 feet or less in depth, (2) where the temperature never falls below about 68° F., (3) where the water has the saltness of normal sea-water, (4) where the water is nearly free from sediment, and (5) where it is subject to some movement by the wind. Where these conditions exist, polyps thrive and make reefs, and the reefs may become islands. Polyps flourish about many tropical islands, and along some continental coasts, as along the eastern coast of Australia.

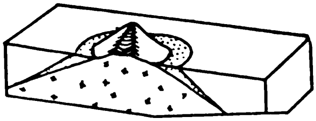

Fig. 464.—Diagram of a fringing reef.

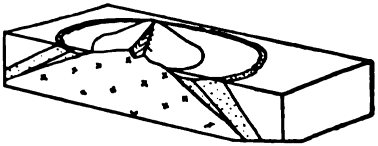

Fig. 465.—Diagram of a barrier reef.

They also flourish in some places far from islands or continents, where there is shallow water of the right temperature.

Figs. 464 and 465 show coral reefs. Those which are far enough from the land to leave a somewhat wide and deep belt of water (lagoon) inside are *barrier* reefs; those close to the land are *fringing* reefs. It seems probable that fringing reefs sometimes become barrier reefs by the sinking of the island or coast where they occur. Where this is the case, the sinking should not go on faster than the polyps build up the reef, that is, but a few inches a century. Barrier reefs arise in other ways also. Coral reefs are usually interrupted where fresh water descends from the land, so that a reef rarely surrounds an island completely, and is rarely continuous for great stretches along any coast.

A barrier reef about a small island may become an island or *atoll* by subsidence (Fig. 466). Coral islands may also arise by the growth of reefs on volcanic cones or other islands which do not rise to the surface of the water.

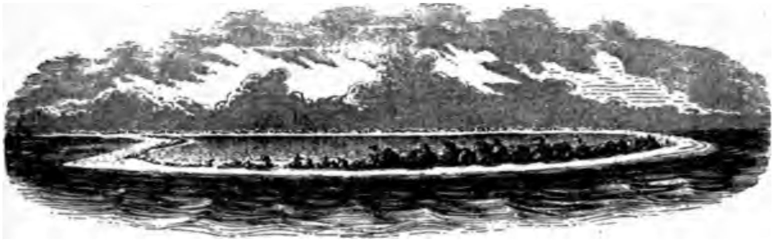

Fig. 466.—An atoll. (From Dana's Corals and Coral Island, by permission of Dodd, Mead & Co.)

The polyps do not build the reef or the atoll above water; but when they have built it up to water-level, the waves may build it higher, much as they convert sand reefs into land. Once land appears, the wind may make it higher by piling up coral sand. The growth of vegetation may help along the building, both by its own growth and by helping the lodgment of wind-blown sediment.

Coral islands and reefs would always remain low if it were not for diastrophism. There are, indeed, no very high coral islands, but there are coral reefs far above sea-level along various coasts.

Either the land where such reefs occur has risen greatly, or the sea-level has been depressed. There are very ancient coral reefs (now limestone) in the interior of continents, as, for example, in eastern Wisconsin, showing that a warm sea once covered this region.

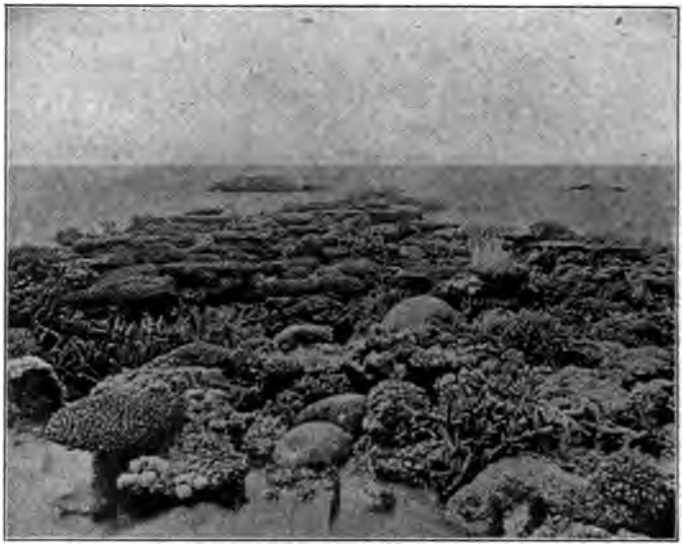

Fig. 467.—Coral growing.

MATERIALS OF THE SEA BOTTOM

The materials of the sea bottom are gravel, sand, mud, shells, coral, etc., and ooze.

Gravel is found chiefly along the borders of the land, out to depths of a few fathoms, or at most a few score of fathoms. Gravel and bowlders, carried out by icebergs, are occasionally found at great depths and far from land. Sand, too, is found chiefly in shallow water, though it extends out to depths greater than those reached by gravel. Mud is much more wide-spread. In general, mud from the land is not washed out far from the shore, but off the mouths of great rivers it is carried out hundreds of miles.

Dredging. The sediment on the bottom of the sea may be brought up to the surface. Various sorts of apparatus are used for this purpose. The cup lead is shown in Fig. 468. *B* is a hollow inverted cone, on a spike. Above the cone is a sliding disc, *D*, a little larger than the base of the cone. This apparatus is let down, and the cone sinks into the soft sediment and is filled with it. On being raised, the disc shuts down on the cup and holds its contents in.

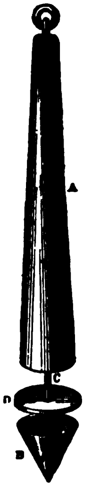

Fig. 468.

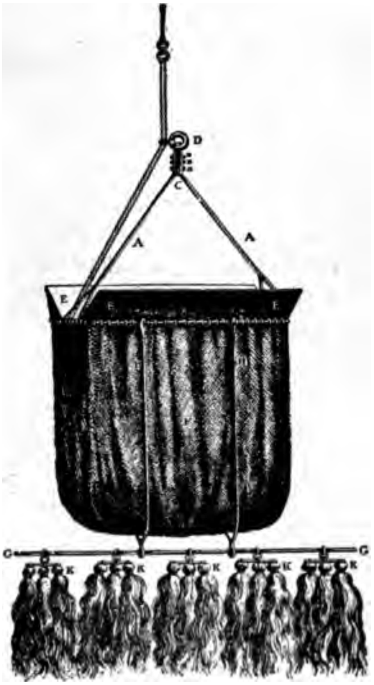

Fig. 469.

Fig. 468.—The cup lead. (Challenger Report.)
Fig. 469.—The dredge. (Challenger Report.)

Fig. 469 shows a *dredge*. The dredge is let down, and the flaring strip of metal *E* is dragged along the bottom, and turns the sediment of the bottom into the sack. Swabs are attached below to entangle small animals missed by the dredge.

By the use of dredges it is known that most of the bottom of the sea is covered with soft sediment. This sediment has come from many sources. Some of it was carried to the sea by rivers, some of it was worn from the shores by the waves, some of it was blown out from the land, some of it is made up of the shells, etc., of the organisms which live in the water, and some of it is composed of fine debris thrown out from volcanoes beneath the sea. A little cosmic ("shooting-star") dust is also present.

The sediments derived from the land came from the land rock. In their present state, however, the sediments of the sea bottom are to be looked upon as rock in the making, for all sediments in the sea may become solid rock by being cemented together. This process is now taking place at many points in the bottom of the sea. In some places it takes place as fast as the sediments gather.

Ooze is the name applied to those soft materials of the sea bottom composed largely of the shells and other hard secretions of tiny organisms which live in the water. Many of these organisms live near the surface of the water, and their shells, etc., sink when they die. Oozes are named from the animals and plants which contribute most to them. Thus *foraminiferal ooze* is the ooze in which shells of tiny animals called *foraminifera* are abundant, and *diatom ooze* is ooze in which tests of minute plants, called *diatoms*, abound. Foraminiferal ooze is much like soft chalk.

Below the depth of about 2,200 fathoms, the ocean bottom is covered with *red clay*. The particles of the clay came from many sources. Some of them were thrown out from volcanoes, some were blown out from the land, some were probably derived from the shells, etc., of marine life, and still others came from meteors.

On the lands there is rock (*conglomerate*) composed of cemented gravel, rock (*sandstone*) composed of cemented sand, rock (*shale*) composed of cemented mud, and rock (*limestone*) composed of material derived from shells, corals, etc. None of these seem to be deep-sea oozes cemented together, and none correspond to the red clay of the very deep sea. In the lands, therefore, there are rocks corresponding to all the sediments now making in the shallow water of the sea, but none corresponding to those of the very deep waters. This suggests (1) that *most lands have been, at some time, beneath the sea*, and (2) that, *so far as now known, no part of the present continents was ever at the bottom of the deep ocean.*

RELATION OF THE SEA TO THE REST OF THE EARTH

The ocean is of great importance to the rest of the earth, in ways which have been pointed out already. By way of summary they may be brought together here.

1. Waves change the coast-lines: they wear away the land in some places and build new land in others. On the whole, destruction exceeds building, so far as the land is concerned. The ocean therefore tends to extend itself at the expense of the land.

2. Oceans modify the climate of the land, affecting both temperature and precipitation. The effect on temperature comes from the fact that water is heated and cooled more slowly than land is. The air over the sea, therefore, has a lesser range of temperature than that over the land, and blowing to the land tends to carry the temperature of the sea over to it. Winds from the ocean make the lands to which they blow less cold in winter and less hot in summer than they would be if there were no ocean.

The climatic effect of the sea on the land is felt most on the west sides of the continents in the zones of westerly winds, and on the east sides of the continents in the zones of easterly (trade) winds. The cold currents of the sea have much less effect than warm ones on the climate of the land, because they lie along the east sides of the continents, so far as they stay at the surface, and in the latitudes where they occur, the winds blow from them to the sea, rather than to land.

3. The ocean is the great source of the water for rain and snow, and its precipitation from the air furnishes the conditions necessary for life on the land.

4. Through its effects on rainfall, snowfall, and temperature, the ocean has an important effect on the erosion of the land.

The total amount of rainfall for the earth is not accurately known. If it is as much as forty inches per year on the average, for the whole earth, and if all this were derived directly from the ocean, an amount equal to all the water in the ocean would be evaporated in about 3,000 years. Since most of the water evaporated from the ocean falls again into the sea as rain, or runs to it in rivers, or comes out beneath it as springs, the amount of the ocean water does not grow less.

5. The ocean yields a large amount of food-stuff every year, and a large amount of other material useful to man. Thousands of people are constantly employed in getting these useful things from the ocean.

6. The oceans play an important part in the commerce of the world, by serving as a great highway.

Oceans were formerly great obstacles to quick communication between the continents separated by them; but during the last half century several cables have been laid connecting Europe and America, so that all the important news of one continent is known in the others almost as soon as it is at home. The work of laying cables across the Pacific has already been begun.

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